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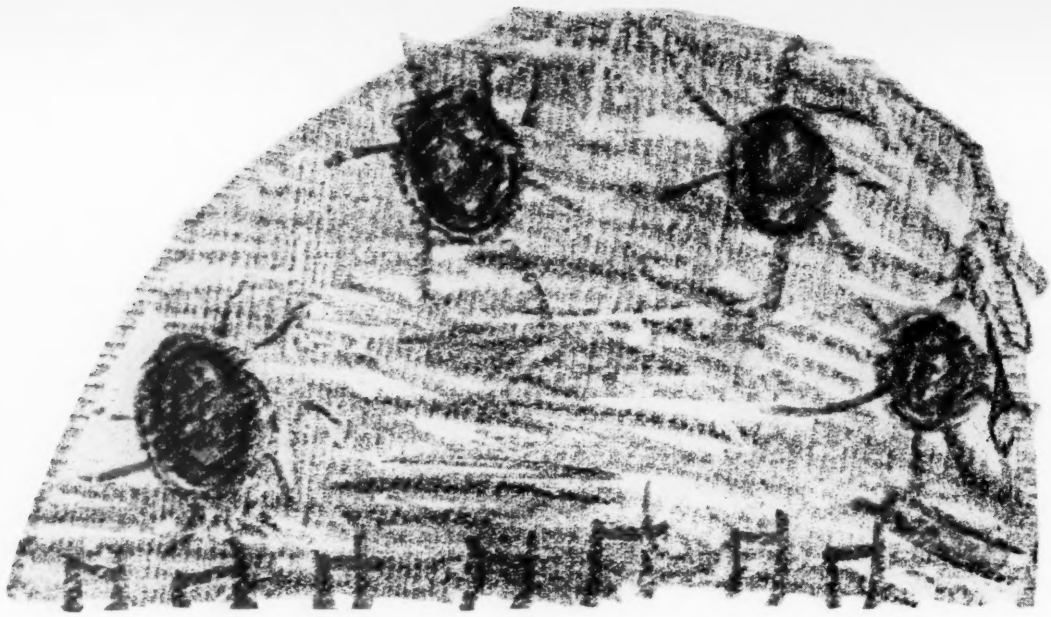

By Mark K., age 7

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1952

PRE-DISCOVERY

NOW IT CAN BE TOLD — the complete story of the Alexander F. Morrison Planetarium at the California Academy of Sciences. To describe adequately this newest San Francisco attraction, in Golden Gate Park, called for a "super-colossal" special issue. Some weeks ago, the editors began to talk tentatively in terms of 40 pages. In the final stages, we regretfully put aside many fine photographs and drawings in order not to exceed a practicable maximum of 48!

This issue is entirely written by officers and staff members of the Academy. It was designed, moreover, to serve as a continuously available source-book of all the essential facts and figures of the Morrison Planetarium and its heart, the Academy projector, which we are not the least reluctant to proclaim to the world as conceived, designed, largely built, and entirely assembled in our own instrument shop by our own personnel.

On behalf of all the editors of *PD*, we wish to give due credit to certain persons and concerns whose coöperation and interest have made this issue a reality. The editor wishes especially to acknowledge the help of a special advisory committee appointed by the Director. It consisted of Ruel Crocker, Academy publicity officer, who helped coördinate all manuscript and photographic material and handled the advertising in and publicizing of this issue; and Leon E. Salanave, astronomer and lecturer in the Morrison Planetarium, who, besides contributing a major article, a short, a book review, and a selected book list, served throughout as technical advisor and constructive critic. This committee, severally and collectively, was constantly at the editor's call. Productionwise, thanks are due to California Art and Engraving Company and James J. Gillick and Company, our plate-makers and printers, respectively, who have given us extraordinary coöperation and service, on a tight schedule, with no sacrifice of their usual high production standards.

DISCOVERING PD'S AUTHORS

THE ACADEMY'S President, **Francis P. Farquhar,** is widely known throughout the West (as a starting point) for his interest in fine books, mountaineering, California history, and the affairs of many prominent organizations, notably the Sierra Club and the Academy. . . . The Director, **Dr. Robert C. Miller,** has served faithfully as the link between Trustees, donors, and the Academy technical staff who have shared from the outset the problems and the ultimate triumph of the planetarium project. . . . **George Bunton,** who came to us from the Griffith Observatory in Los Angeles, worked many months as one of the chief technicians before taking on the managership of the Morrison Planetarium. . . . **A. S. Getten** ("Jimmie" to his colleagues in the shop) is, though you would never know it from him, more than anyone else the creator of the Academy projector. It is still a mystery how he found time to write a detailed technical description during the final rushed weeks of assembling the instrument. . . . **Leon E. Salanave** was entrusted with the difficult and decisive task of mathematical computation behind the astronomical precision of the projector, while he was professor of astronomy at Sacramento State College. Now on the Planetarium staff, he shares lecturing duties with Mr. Bunton. . . . The **Greebys** will be much missed by all the staff; shortly after "Reet" finished her delicate job on star plates, Ray was appointed instrument maker at the Lick Observatory. This skilled young couple now enjoy closer proximity to the real stars — their new home is atop Mt. Hamilton. . . . **Dr. Earle G. Linsley's** Astronomy department of earlier issues has come to full flower in this special number! The Academy research associate in astronomy was for many years the popular lecturer of Oakland's Chabot Observatory. . . . **Benjamin Draper's** regard for his Profile subject developed through the close association of executive producer and guest scientist for the Academy TV show, "Science in Action." . . . Two other contributors, whose bylines scarcely show, must be mentioned. **Herbert Jow,** whose exquisite drawings illustrate Mr. Getten's article, has served from the start as draftsman on the Planetarium staff; **Elmer Moss's** magnificent photographs really make this issue. D.G.K.

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THE COVER COPY

THE ACADEMY PROJECTOR in the Morrison Planetarium, southern hemisphere. Planet cages, reading up from the hemisphere, are: Mercury, Venus, Saturn, Jupiter. Photograph by Elmer Moss.

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FARTHER HORIZON

THE OBVIOUS PURPOSE of a planetarium is to demonstrate by mechanical means the movements of the planets, including Earth, around the sun and in relation to each other. Early in the eighteenth century such a mechanism was devised for the Earl of Orrery and was called by his name. This simple clockwork device did little more than indicate the orbits and relative speeds of the respective planets. It could not, of course, be true to scale, for no chamber could contain the orbit of Saturn, or even of Jupiter. Nevertheless, the "orrery" was an effective instrument to demonstrate the scientific work of such men as Newton and Halley, for it enabled the layman to form some concept of what the learned men of the Royal Society were talking about. There is no doubt that visual demonstration of this character helped create in England and in Europe an attitude receptive to the announcements of new discoveries and ideas in the natural sciences.

Since the eighteenth century, men of science have multiplied so enormously the variety and range of knowledge of the physical universe that the layman still finds himself in need of a visual demonstration to aid his comprehension. The primitive planetarium, or orrery, no longer suffices; but mechanical advancement has kept pace in some measure with the advancement of science. Today the highly complex, precisely made modern planetarium, produced first in Germany and now in this country, is available to us.

The understanding layman, himself, has multiplied to include a vastly greater portion of the population than in the days of Sir Isaac Newton and Lord Orrery — multiplied to include children as well as men and women of all vocations. Again, the layman is able to see for himself in a comprehensible model the components of the solar system of which he now knows his earth to be a harmonious part and not a self-sufficient and dominant feature.

The mechanical qualities of our modern planetarium are readily perceived and their perfection accordingly admired. The instrument fulfills the original purpose even more adequately than might be expected. We have added the starry firmament to our view and the planets move against their accustomed background. But we have added something more, something vitally needed in an age often called materialistic. We have added another purpose for our twentieth century planetarium, and this purpose is the enlargement of the mental horizon. For who can sit in the darkened chamber and watch the stars come out till the illusion is complete without beginning to dream of things beyond the scope of the physical senses, seeking to penetrate beyond time and space? Emerging into the light of day the visitor will go his way with a better understanding of himself and his neighbor.

If such, indeed, be the case, the Academy's Morrison Planetarium will far exceed in its influence the mere study of the mechanics of planetary movement. It will help man fulfill himself.

Francis P. Farquhar

President, California Academy of Sciences

EDITORIAL

Ad Astra per Aspera

TO USE A LATIN MOTTO in the middle of the twentieth century is to invite two kinds of criticism. Some will think it archaic and wilfully obscure; others will consider it trite and banal. There may also be some comments from a third source, to be mentioned in our next issue. Nevertheless we cannot forego the opportunity of using a Latin motto that seems so completely applicable to the building of the Alexander F. Morrison Planetarium.

"To the stars through difficulties" is the translation commonly given. But since the basic meaning of "asper" is "rough," we venture our own translation, "To the stars in spite of some rough going."

Ten years ago it is doubtful that anybody in the world thought San Francisco would have a planetarium in 1952. Six years ago the Academy's Trustees, encouraged by certain conditional subscriptions as explained elsewhere in this issue, decided to try to raise the necessary funds. The task seemed formidable, and there were prophets of gloom who said it wasn't even worth while to try. But the Trustees had faith in the project and believed the funds could be obtained. They persisted in spite of obstacles, and they succeeded. The money was raised.

Even then there were many difficulties to be overcome. There were problems of planning, of selecting a site, of obtaining the approval of two city commissions and the Board of Supervisors. It was even necessary to amend the San Francisco Charter, requiring a vote of the people and approval by the State Legislature. All of this was accomplished in due course.

Last but far from least was the problem of obtaining a star projector, the immensely complicated instrument that accurately depicts the positions and movements of the stars, the sun and moon, and the planets. How this problem was solved is described in detail in the following pages. Suffice it to say here that it took more than four years of unremitting toil and inventiveness by the staff of the Academy's instrument shop, working six and sometimes seven days a week, to construct the first instrument of this type ever made in the United States.

Sometimes the going was rough, but the objective was never lost sight of. And when at last, on a late afternoon in the autumn of 1952 – after weeks of adjusting and testing of the projector – the staff gathered in the planetarium chamber and for the first time the stars were turned on, there was a vast, deep sigh of mingled relief and joy, and some quiet tears were shed under cover of the welcome darkness.

"Ad astra per aspera" is a motto which, while peculiarly appropriate to the building of the Morrison Planetarium, may be applied to the Academy's activities in a wider sense. It might well have been the motto of the men who founded the California Academy of Sciences ninety-nine years and seven months ago; surely in establishing such an institution in a pioneer community in 1853, they expected, and encountered, some rough going. It may well be our motto as we look to the years ahead.

Though much has been accomplished, much remains to be done. Past success should be only a spur to greater achievement in the Academy's ever-widening field of scientific activity and public service.

We need a new library building to house our outstanding scientific library which, because of crowded conditions, is only inadequately available to scientific workers and hardly at all to the public. We need additional exhibit halls. Of the Academy's seven research departments, only two or three are adequately represented by public exhibits. We have, for example, the largest and most important collection of insects west of the Smithsonian Institution, but no public Hall of Insect Life. We have the largest collection in the world of animals and plants from the Galápagos Islands, but not a single public exhibit of the unique flora and fauna of these detached islets that William Beebe has dramatized with the phrase, "World's End."

We need expanded quarters for our crowded research departments. We need endowments for these departments, similar to the Alvord Botanical Bequest and the Alice Eastwood Herbarium Fund. We need more funds for scientific publication, one of the Academy's special functions. We need more funds to provide free educational services to the public, along the lines of the Dr. Walter B. Scaife Foundation for Lectures on the Beauties of Nature. We need special gifts for scientific equipment, for expeditions, for research projects beyond our present means.

More important than any other need, perhaps, is our need for an endowment for our Student Section. Started twelve years ago on little more than faith and hope, this has become one of our most vital activities. Its objective is to make available to young people with scientific interest and ability the resources of a great museum, for the encouragement of their natural bent. Already the earlier members of this Section have gone through college and graduate school, are publishing scientific papers, and holding responsible scientific posts. We believe that this activity is deeply important, for out of it will come scientists of the future—always, we hope, striving toward the stars. R.C.M.

Fig. 1. The Farnese Globe, a fine piece of sculpture found in Italy and dated prior to 73 B.C.

THE HEAVENS

THE MODERN, complete, projection planetarium, exemplified first by the famous Zeiss instrument and now by the projector in the Alexander F. Morrison Planetarium, is the end product of a gradual transition of thought and a slow development of theoretical concepts of the universe. It represents the high skill and ingenuity of modern man in his effort to convey, by means of a model, the structure and behavior of the universe. It is an instrument for instruction, a theater for entertainment, and a vehicle for the mind to ride to the limits of the universe.

The effect of realism is the keynote of the modern planetarium. In the Planetarium Theater, with the waning of the room illumination and the appearance of the starry heavens, the watcher is transported magically to the out-of-doors. His senses interpret the spectacle as the real thing. Tiny spots of light, projected onto the white dome ceiling, resemble the stars themselves to such an extent that one can easily be carried away with the illusion till he feels the chill of the night air.

The purpose of the planetarium is not alone to reproduce the universe indoors, but to provide a means of instruction in the realm of astronomy through control of the rate of movement of the heavenly bodies. Through ages of time, men have observed the motions of the sun, moon, planets, stars, and other less common bodies, and have described their apparent motions and analyzed those motions to determine how the universe functions. To make his observations and conclusions known to other men, the astronomer has mainly to rely upon words. The pragmatic layman demands to be shown quickly and efficiently and has too little time or interest to wade through a sea of words to learn what the astronomer has found. A picture is worth a thousand words, it has been said; certainly a working model is worth many pictures. The planetarium affords the opportunity of seeing the planets in motion, speeded up so their motions are obvious in a few minutes instead of a lifetime.

Surely the oldest of the sciences is astronomy. The first man with eyes to see and a mind to think

GEORGE W. BUNTON

IN OUR HANDS

For two thousand years men have dreamed up devices to bring the mysteries of the celestial bodies down to their grasp

studied the rising and setting of the sun, the phases of the moon, the cycle of the seasons, and the motions of the bright planets among the stars. He was unable to interpret those motions, but he went abroad by day and kept time by the sun and the moon. He knew that as a backdrop for those wandering actors of the sky hung the unmoving stars. The stars and their arrangement in the sky were the same year in and year out. The configurations of the stars became familiar to him and he gave some of them names. Thus the constellations were born.

The urge of creative art dwelt early in man. Evidence of his earliest efforts is found on the walls of caves occupied by prehistoric races. As higher cultures evolved, the objects of art became more abstract. The deities of man were hewn from stone. Early concepts required that the earth be supported somehow, and it was logical to assume it to be rested upon the shoulders of a god. One of the earliest celestial globes is the Farnese Globe (figure 1), one of the world's finest astronomical sculptures. It is a white marble figure of Atlas supporting the celestial sphere upon his shoulders. This fine piece was found in Italy and is dated earlier than 73 B.C. Many of the constellation figures we know today are sculptured in relief on the surface of the globe, and the path of the sun is marked by parallel lines. We might well consider this figure or its like the beginning of the development of the planetarium.

Many globes and charts of the heavens were wrought through the ages and in many parts of the world. Perhaps we should consider the first real "instrument" of astronomy to be the armillary sphere (figures 2 and 3, next page). Argument is possible upon this point, for the gnomon, such as Cleopatra's needle, probably antedates the armillary sphere. However, Edward L. Stevenson, in his second volume of *Terrestrial and Celestial Globes,* mentions an unreliable record of an armillary sphere being used by the Chinese Emperor Shun who reigned more than 2,000 years before the Christian era. The armillary sphere is the skeleton of the celestial sphere. It consists of a framework of circular rings mounted to represent the various astronomical circles in the sky. A horizontal ring represents the horizon, another ring marks the equator, another the ecliptic, or path of the sun, and a vertical ring standing north and south marks the meridian.

Armillary spheres were produced that were marvels of craftsmanship and art. One of the most famous is the Gottorp armillary sphere reportedly built in 1657 by Andreas Busch for Frederick III of Holstein-Gottorp (figure 3). This instrument was mechanized to permit the movement of a brass ball representing the sun and six silver angels mounted on concentric rings representing the known planets and their orbits. It is notable that the earth was included as one of the planets at a time when this was still somewhat of a controversial subject. Supported on the outer rings of the armillary sphere were bronze figures of the constellations upon which were placed the brighter stars in silver. The part of the framework bearing the equator was made to rotate with respect to the ecliptic or zodiac at a rate corresponding to one revolution in 25,000 years, which is the rate of the precessional motion of the earth.

The motions of the planets were more accurately duplicated a few years later in a mechanical planetarium built by the famous clockmaker, Johannes van Cuelen de la Haye, after a design by the great mathematician Christian Huygens. The problem of computing the gear trains to impart the correct relative motions to the planets was solved by Huygens, and in so doing, he gave to the mathematical world the process of continued fractions. The same problem arises and is solved by the same means in designing the gear trains for the modern planetaria.

Early in the 18th century a fine mechanical planetarium was constructed by John Rowley for Charles Boyle, fourth Earl of Orrery. The instrument was called an "orrery" in Boyle's honor, and similar instruments have borne the same name ever since (figure 4). Such devices represent the

"new" concept of the solar system proposed by Copernicus. The early Greeks believed that the earth was round and that it moved around the sun once a year, but this idea was discarded by later people because, they argued, since the celestial sphere obviously surrounded the earth, the earth must surely be the center of the universe and therefore stationary.

Returning for a moment to the 17th century, we must mention another remarkable device which had a tremendous influence upon the history of the planetarium. It is known as the Gottorp Globe. The same Andreas Busch, the maker of the Gottorp armillary sphere, was the builder of the globe. It was constructed concurrently with the armillary sphere and was probably finished in 1664. It was a globe, 11 feet in diameter, weighing 3.5 tons, and built to accommodate 12 persons in its interior. The exterior bore a map of the earth, and on the interior surface was a map of the sky punctuated by gilded stars. A platform was supported inside the globe upon which the observers could stand and view the sky map as it should appear from the earth. All other globes had shown the sky from the unnatural position of the observer on the outside of the celestial sphere. The globe was originally driven by water power to rotate once in 24 hours.

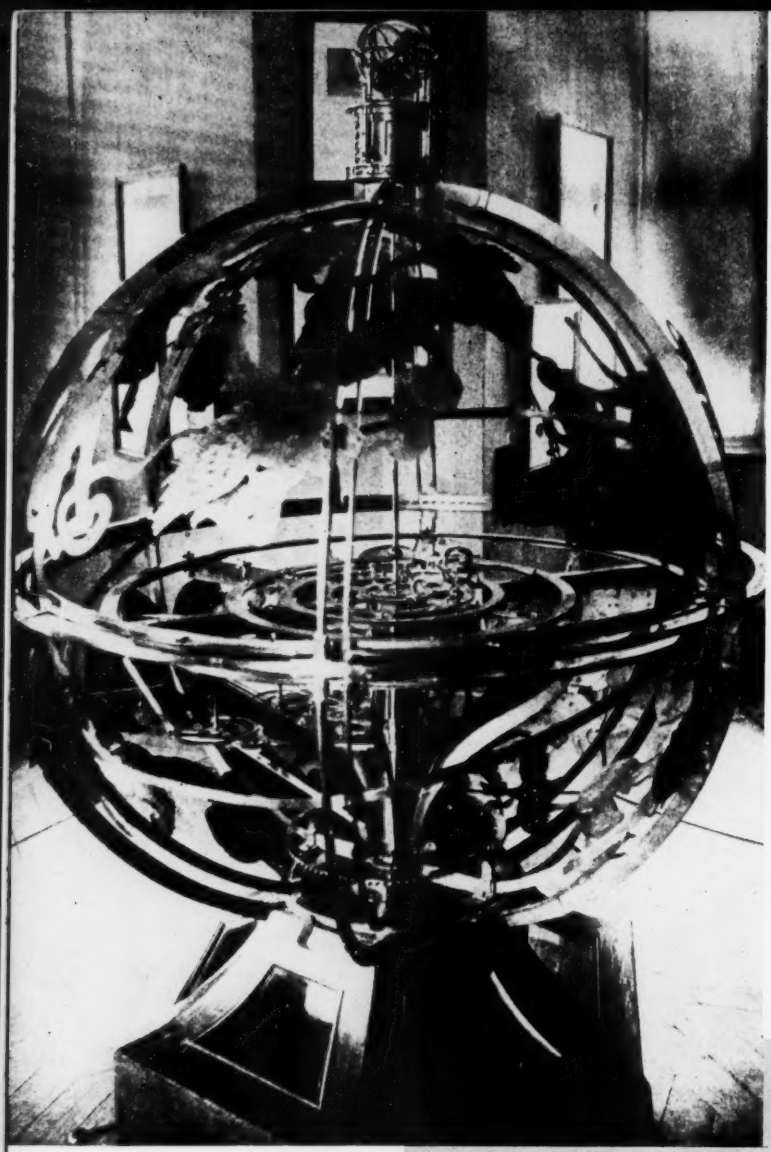


Fig. 2
The famous Gottorp armillary sphere of Andreas Busch, probably built in the year 1657.

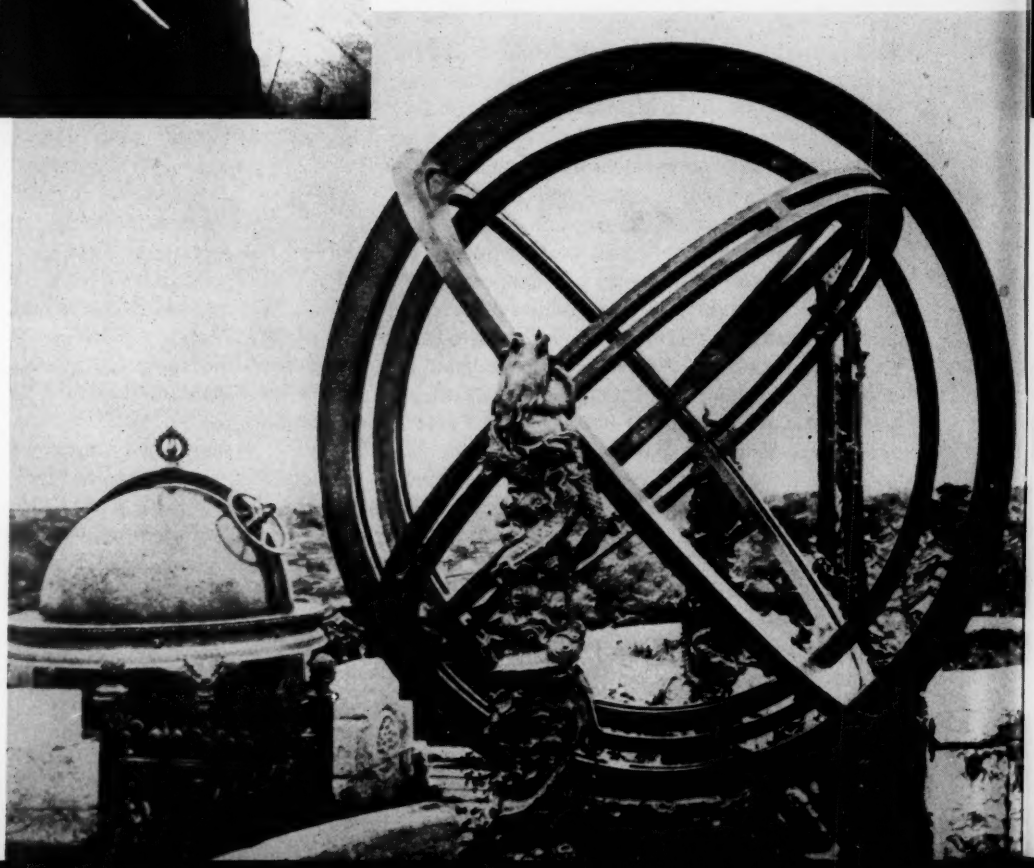


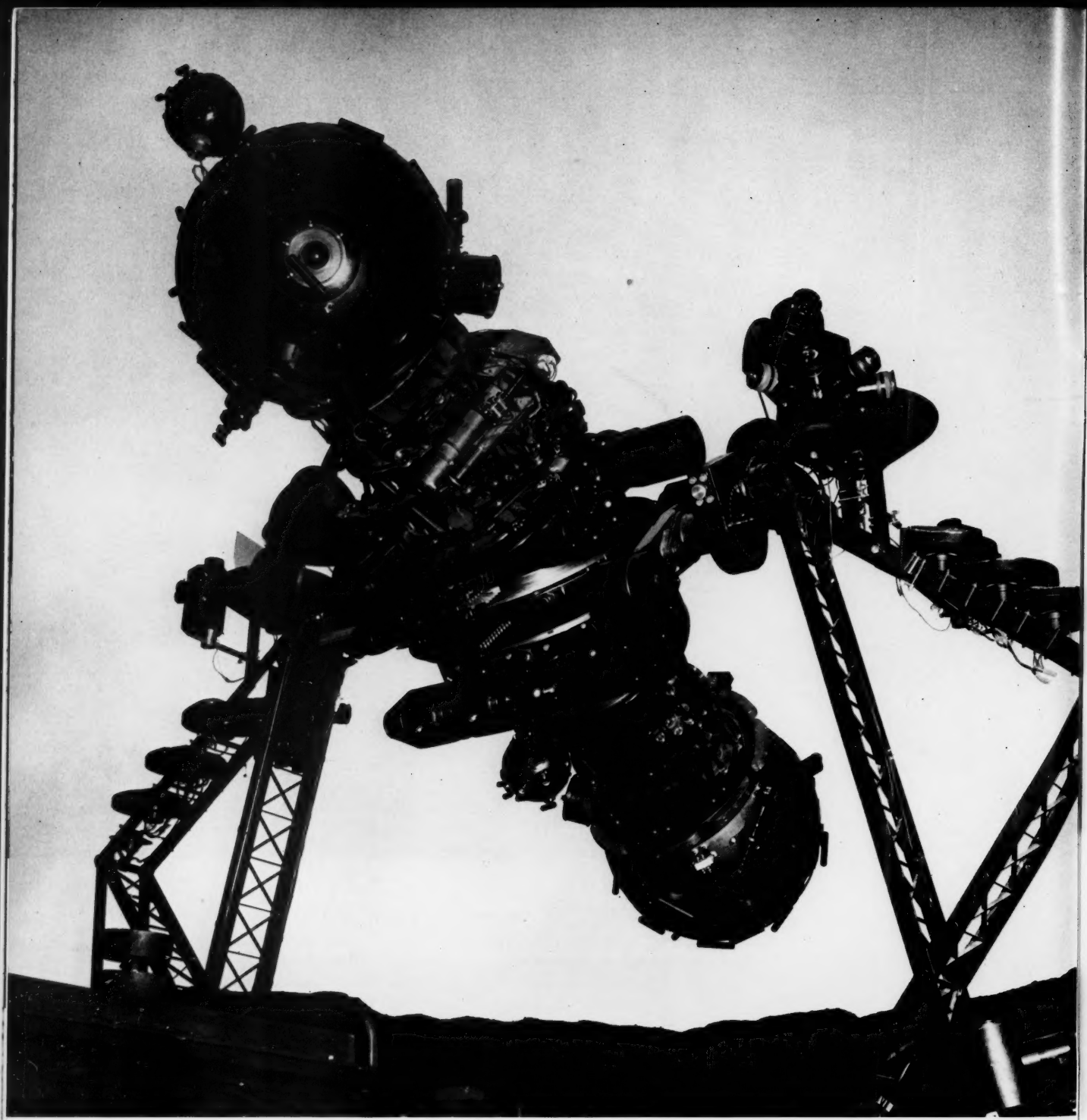
Fig. 3
An armillary sphere and celestial globe designed by the Jesuit astronomer Ferdinand Verbiest and built for the emperor of China in 1673.

Another large globe was the "Astronomical Machine" of Roger Long, constructed about 1758. Long was professor of Astronomy at Cambridge. The globe was 18 feet in diameter with an interior platform accommodating about 30 people. The globular shell was perforated with holes of various sizes. When illuminated from the outside, the stars appeared to have the proper relative brightnesses. Provision was made to permit a light representing the sun to be moved along the proper path among the stars. This is a very close approach to the modern planetarium. The globe was finally removed and destroyed after about 120 years. One can't help but wonder what will be the fate of the modern planetaria in the next 120 years.

In 1911, Dr. Wallace W. Atwood, president of Clark University and director of the Chicago Academy of Sciences at the time, designed a globe similar to that of Roger Long. It was constructed 15 feet in diameter and is electrically driven. It also shows the motions of the sun and moon. The instrument was presented to the Academy by La Verne W. Noyes, then president of the Board of Trustees of the Chicago Academy. This instrument is still in use today.

It is easy to see the difficulty of constructing a globe of this sort to accommodate a much larger audience. It was this difficulty which prompted the proposal of the optical planetarium. The problem of designing a huge sphere to accommodate a

Fig. 4. "The Philosopher reading a lesson on the Orrery," a reproduction of a rare mezzotint by William Pether after a painting by Joseph Wright, made in 1766 for the Earl of Ferrers, and shows members of the Earl's family grouped around the device named for the Earl of Orrery. (Photograph reproduced through the courtesy of Harry Shaw Newman, The Old Print Shop)



large group of people and to provide means of showing the motions of the planets as well was brought to the Zeiss optical firm. No satisfactory solution was found "... to create the illusion of the mysterious, silent march of the worlds of nature." The idea of optical projection was suggested by

Fig. 5. The Zeiss projector in the Griffith Planetarium, Los Angeles. (Elmer Moss)

Dr. Bauersfeld of the Zeiss company shortly after the end of World War I. His proposition is explained in his own words:

"The great sphere shall be fixed; its inner white surface shall serve as the projection surface for many small projectors which shall be placed at the center of the sphere. The reciprocal positions and motions of the little projectors shall be interconnected by suitable driving gears in such a manner that the little images of the heavenly bodies, thrown upon the fixed hemisphere, shall represent the stars visible to the naked eye, in position and motion, just as we are accustomed to see them in the natural clear sky."

In August of 1924, after fully five years of design and construction in the huge Zeiss plant in Jena, the first instrument emerged. The results were surprising even to those who had designed and constructed it. The illusion of reality was excellent, and the motions of the heavenly bodies could be simulated accurately and at a greatly accelerated rate.

The first model was limited to the reproduction of the sky at only one northern latitude. Only two of the first model were built. One of them is in use today in The Hague, Netherlands. It wasn't long before Dr. W. Villiger of the Zeiss company suggested a means of changing the design of the machine to allow it to produce the sky as seen from any latitude. About 25 of the later model were constructed, most of which are in Europe (figure 5). Thus far, six have been installed in the United States. They are listed here in order of the dates of installation:

Adler Planetarium, Chicago, Ill., July 5, 1930.
Fels Planetarium, Philadelphia, Pa., Nov. 6, 1933.
Griffith Observatory, Los Angeles, Calif., May 15, 1935.
Hayden Planetarium, New York, N.Y., Oct. 3, 1935.
Buhl Planetarium, Pittsburgh, Pa., Oct. 24, 1939.
Morehead Planetarium, University of North Carolina, Chapel Hill, N.C., May 10, 1949.

The instrument at Chapel Hill was formerly in use in Stockholm, Sweden. The Zeiss company did not produce any instruments of this sort in the war years except for some smaller instruments used for training of pilots and military personnel in star identification and navigation. One such instrument has been on display in the Hall of Science of the California Academy of Sciences in San Francisco for some time.

The Zeiss type instrument is now in production by the Ercona Works in the Russian zone of East Germany. It is built upon the original design with some claimed improvements.

A few other planetaria of lesser complexity have been designed and built in the United States, notably the Spitz, the Peerless (figure 6), and the Korkosz. Few attempts have been made to construct a planetarium with the versatility and accuracy of the Zeiss instrument. The outstanding exception is the projector in the Alexander F. Morrison Planetarium. END

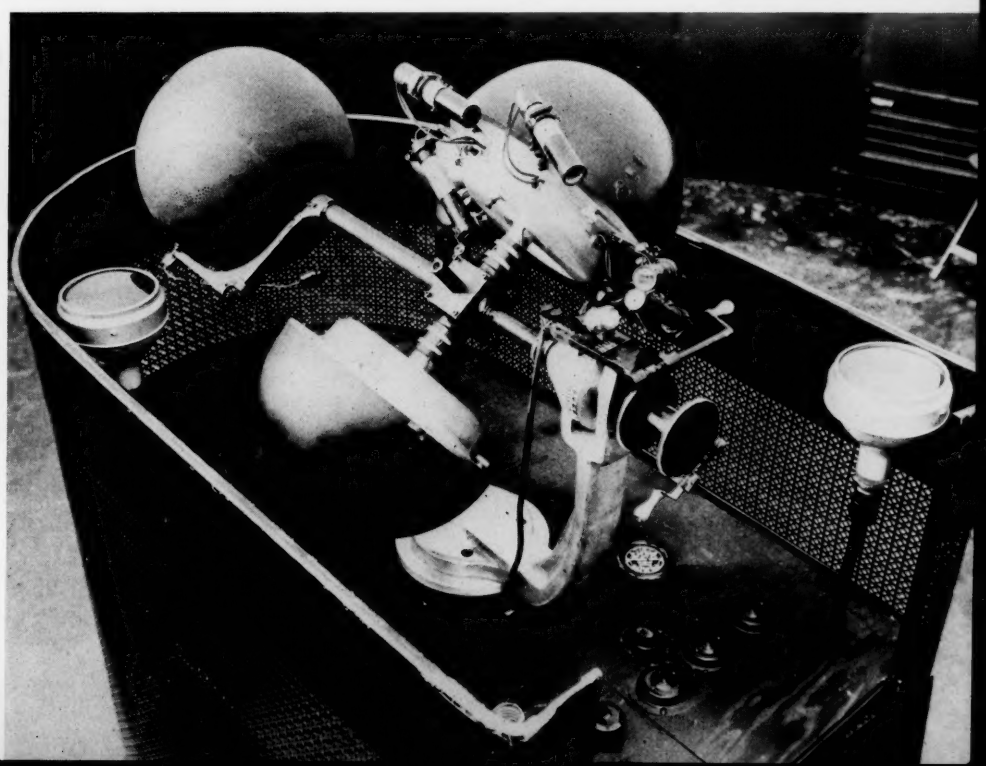
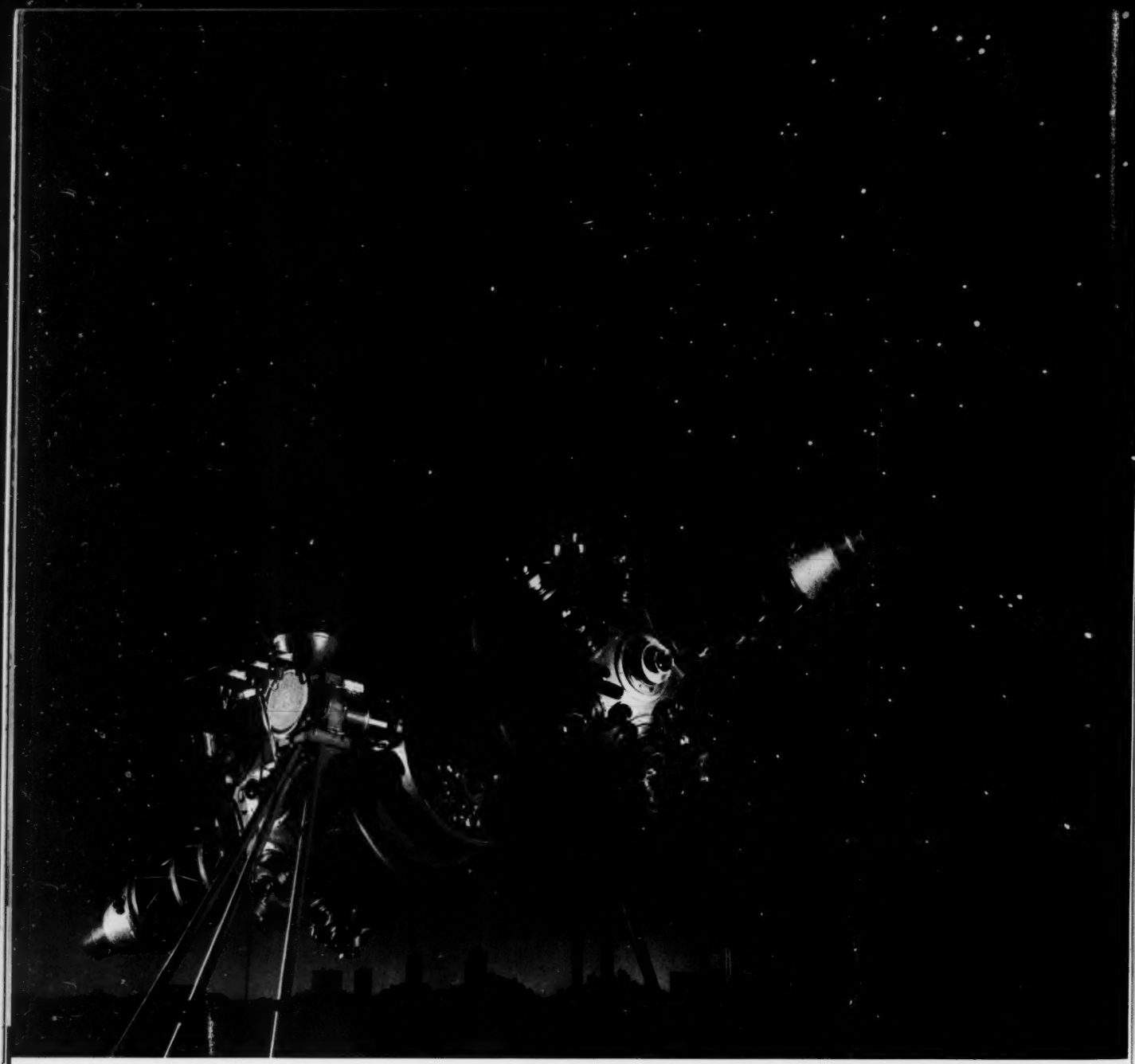


Fig. 6. The Peerless Planetarium installed at the Polytechnic Institute of Puerto Rico, San German, P.R.



A planetarium for San Francisco! —
How the idea of the Alexander F. Morrison Planetarium,
the skill to design and build it, and the generous financial
support, met in Golden Gate Park

Never was a medium of demonstration produced as instructive as this, never one more fascinating in effect, and certainly never one which appeals to everybody as this does. It is a school, theater and film all in one, a lecture hall under the vault of the heavens and a drama in which the celestial bodies are the actors. No description, no photograph, no drawing can possibly reproduce the overwhelming impression made by a demonstration in a . . . planetarium. . . .

DR. E. STRÖMGREN, *former director, Copenhagen Observatory*

GALAXY BY THE GOLDEN GATE

ROBERT CUNNINGHAM MILLER

IMPORTANT IDEAS are rarely the product of a single mind. Most commonly they represent a synthesis of the thought and effort of a number of persons, sometimes working independently, sometimes together, and often over a considerable period of time. Such was the history of the steam engine, the automobile, the airplane; of the development of the electrical industry; of atomic fission; and of radar, with which we can signal to the moon and get an echo back. Such was the development of the modern planetarium out of the orrery and other devices for depicting celestial bodies and their motions, as described elsewhere in the present publication. Such also was the story of the Morrison Planetarium itself.

Before the fact, a dream

When this writer became associated with the planetarium project half-a-dozen years or so ago, he was under the impression that this was a new undertaking for the California Academy of Sciences, and that it might meet with opposition from some who would consider it outside the Academy's sphere of interest and activities. To his surprise, he found correspondence in the files indicating that Dr. C. E. Grunsky, former president of the Academy, had been interested in a planetarium as early as 1932, and had accumulated considerable information regarding Zeiss planetariums and their cost. It is not unlikely that the idea had been suggested to Dr. Grunsky by Dr. E. P. Meinecke, then vice-president of the Academy, who had seen and been much impressed by the Zeiss installation in Munich.

Before any definite plans had been formulated, Dr. Grunsky's death intervened and the whole matter was dropped and forgotten. The idea, when it recurred a number of years later, was quite independent of this first interest; it came from several sources at about the same time, and involved a very interesting chain of circumstances.

In 1943 the Academy entered into a contract with the United States Navy to repair optical and navigation instruments and to manufacture the necessary optical and mechanical parts. This may well be one of the most unusual activities in which an academy of sciences has ever engaged, and it was in fact a desperate undertaking in desperate times. The armed forces were caught short, with a vastly expanded need for optical and precision instruments of all kinds and with foreign sources that had previously supplied much of the American market abruptly cut off — in fact, at war with the United States.

The Academy, for its part, had two key men available: Dr. G. Dallas Hanna, curator of the department of paleontology, who as a side line of his professional interest had become an authority on optical instruments and had made numerous improvements in the use of the microscope; and Mr. Albert S. Getten, an experienced instrument maker and designer. The Academy had also, through Dr. Hanna's interest in such matters, a small but well-equipped instrument shop, which served the institution's needs for making or repairing research equipment.

From these beginnings there grew a rather astonishing project. Tons of fossils were moved out

of the department of paleontology had stored elsewhere to provide working space adjacent to the existing shop. Work benches and additional machinery were moved in.

Help was trained under Dr. Hanna's supervision. Hidden talents began to appear, and various members of the Academy's staff became expert instrument workers. Joseph R. Slevin, curator of herpetology and an old submariner of World War I, closed his department for the duration, shipped all type specimens to an inland university for safekeeping, and became a foreman in the shop. W. M. Chapman, curator of fishes, put in long hours as a binocular repairman. Robert P. Dempster, aquatic biologist, proved able to handle some of the most exacting jobs. Benjamin T. Culleton, operating engineer in the Aquarium, worked in the shop several hours a day at the conclusion of his regular shift. Outside help was also engaged, and at the height of the war fifty people were employed on a project that had started out with two.

One serious problem developed – shortage of personnel who knew how to work with glass. It proved fairly easy to develop biologists into precision instrument workers; but only Dr. Hanna knew how to take a piece of optical glass and grind and polish it into a lens, a prism or an optical flat, and the technique was not easily acquired by others. From a long-time friend of Dr. Hanna, A. G. Ingalls of the editorial staff of the *Scientific American,* came a suggestion: "Try the amateur telescope makers. The people who have made telescopes in their own basement shops know how to work with glass."

So the Academy began recruiting the amateur telescope makers, and what a wonderful crew they turned out to be—Carl E. Wells, a Southern Pacific freight conductor (on request of the armed forces, the S. P. gave him a leave of absence to work for the Academy); J. E. Steinbeck, a Western Union teletype specialist (since deceased; one of his fine telescopes is on exhibit in the Academy's Museum); D. A. McLaren, a marine engineer; Allyn G. Smith, an executive of the Pacific Telephone and Telegraph Company; C. C. Church, paleontologist for the Associated Oil Company; L. A. Parsons, chief engineer for the Calaveras Cement Company.

This writer, though not in any sense a skilled instrument worker, spent many evenings in the shop with Dr. Hanna and his telescope makers – doing such chores as he was able. Plenty of work was accomplished – the record shows that 10,000 optical parts were manufactured – but there was also conversation, as men will converse to ease the nervous tension of long hours of precision work. And almost invariably the conversation turned to planetariums.

San Francisco should have a planetarium, the amateur astronomers said, and the Academy should build it. There were long debates as to where it should be located, whether at the Academy or on one of several adjacent hills. Subsequently, when the location of the planetarium became a matter of public debate, this writer had a peculiar advantage – he had heard all the possibilities argued by experts!

All of this conversation was, of course, merely wishful thinking. It was known that planetariums were expensive, and everybody agreed that San Francisco should have nothing but the best. But nobody had any idea where the money might come from – if it came at all.

Putting the foundations under

"If you have built castles in the air," wrote Thoreau, "your work need not be lost; that is where they should be. Now put the foundations under them." This is something very close to a thumbnail sketch of the way San Francisco's planetarium came into being. As a matter of fact it became possible to translate the dream into a reality a good deal sooner than any but the most optimistic expected.

Scarcely had the war come to an end when, out of a clear sky, Mr. C. M. Goethe of Sacramento, a long-time member of the Academy and a frequent contributor to its activities, offered to finance an educational and promotional campaign to raise funds for the building of a planetarium in San Francisco. While the Trustees had this under consideration, another proposal came from a wholly different quarter. Mr. Edward Hohfeld, executor of the May T. Morrison estate, had charge of certain funds for charitable and philanthropic purposes, subject to his discretion. Mr. Hohfeld offered to make available the sum of $200,000 from the Morrison estate, conditional on the Academy's undertaking to erect and complete a planetarium to be named, in honor of Mrs. Morrison's husband who had predeceased her, the Alexander F. Morrison Planetarium.

With a planetarium thus so definitely within the range of possibility, the Academy's Trustees de-

cided to accept Mr. Hohfeld's offer and to put on a campaign to raise the necessary additional funds to complete the project.

Mr. Goethe, far from being disturbed at the turn events had taken, expressed much gratification that a planetarium campaign was under way, and subsequently exceeded his original offer and made a large contribution to the planetarium fund in memory of his wife, the late Mary Glide Goethe, who had shared his interest in a planetarium for northern California.

Other contributions, large and small, came in from numerous sources. Great public enthusiasm developed. A group of 177 prominent citizens agreed to sponsor the undertaking. The newspapers were uniformly friendly, and gave both news and editorial space to the proposed planetarium. The Rosenberg Foundation, prohibited by its set policies from contributing to a building fund, made a substantial contribution to construction of the star projector. The Columbia Foundation, similarly restricted, offered a fund for lectures in connection with the new planetarium. Literally thousands of persons contributed according to their means to what had become a real community project. Even the school children contributed their pennies and, remarkable to state, nearly $10,000 came from this source alone.

The Academy's Trustees, under the energetic leadership of their President, Mr. J. W. Mailliard, Jr., were tireless in their efforts to promote the campaign. Through these combined efforts some $300,000 was raised in addition to the $200,000 offered from the Morrison estate; and with more than half-a-million dollars in hand, the Trustees were able to announce that the project was assured and that the Aleaxnder F. Morrison Planetarium would be built. What had started out as a castle in the air now had a solid foundation.

Morrison Planetarium, Hall of Science

Many people have expressed surprise that a planetarium could be built for half-a-million dollars, inasmuch as all of the six previous planetariums in this country cost substantially more. The Morrison Planetarium would have cost a great deal more if it had been erected as a separate establishment, with its own foyer, exhibit halls, administrative offices, and various necessary facilities. Great economies were effected by erecting it as part of a larger building.

Leslie Simson, who died in 1939, left most of his

The author, Mr. A. S. Getten, and Dr. G. Dallas Hanna at work on plans for the star projector. (All photos in this article are C.A.S. Photos — Moss Studios, San Francisco)

estate to the Academy for completion of the Simson African Hall, the first unit of which had been erected during his lifetime. Mrs. Morrison, who died in 1939, bequeathed $150,000 to the Academy for the erection of an auditorium in memory of her husband. Mrs. Lovell White of Mill Valley, who died in 1930, had left a sum of money for a memorial to her husband, without specifying exactly what type of memorial she had in mind; the trustee of the estate became convinced that a museum hall would be a suitable memorial, and was willing to make the bequest available to the Academy for the building of a hall to be known as "The Lovell White Memorial Hall of Man and Nature."

These sums aggregated in amount about the same as the planetarium fund; and by putting all the eggs in one basket, the Trustees were able to erect a Hall of Science costing $1,100,000, in which were incorporated all of the features mentioned. The Morrison Planetarium and the adjacent Hall of Astronomy occupy about one-half of this building, and account for a corresponding proportion of its cost.

Before construction was started, considerable discussion arose in various quarters regarding the location of the planetarium. Numerous suggestions were offered, either in letters to the Academy or in letters to the press. One correspondent wanted it located in the East Bay. Another thought Alcatraz Island would be the ideal spot! Persistent pressure came from people who wanted it located on Twin Peaks.

To all of these suggestions the Academy had one answer: The funds available were sufficient to erect a planetarium in conjunction with the existing buildings in Golden Gate Park; they were not sufficient to erect it anywhere else. The logic of this was unassailable, and the San Francisco Supervisors, whose approval was required by the city charter, agreed to the location proposed by the Academy.

A unique educational center

The placing of the planetarium in Golden Gate Park was not, however, a mere compromise with economic necessity. The Academy's Trustees were convinced that this was the best possible location in any case, from the standpoint of public convenience and enjoyment. All of the other locations suggested were difficult of access and most of them windswept and subject to considerable fog. Golden Gate Park is visited by more people in the

The new Hall of Science, showing the Planetarium dome and the California Academy of Sciences Special Meteorological Station of the U. S. Weather Bureau.

course of a year than any other public attraction in San Francisco. People are accustomed to coming here on every possible occasion, and will visit the planetarium more freely and frequently than if it were located anywhere else in the city.

Golden Gate Park is distinguished not only as an impressively beautiful area for outdoor recreation for the residents of a busy city; it is distinguished also for its contribution to the cultural life of San Francisco and the Bay Region. It contains the famous Conservatory that James Lick had imported from England and shipped around the Horn. It contains the Strybing Arboretum. It contains the outdoor Music Concourse, flanked on one side by the M. H. de Young Memorial Museum and on the other by the California Academy of Sciences, with its research laboratories and its extensive public exhibit halls, including the Steinhart Aquarium.

With the addition of the Morrison Planetarium to the Academy's other facilities, San Francisco will have as a part of its cultural center in Golden Gate Park an institution for public education and enjoyment which we believe has no parallel elsewhere in the world — a great museum of science, a large public aquarium, and a major planetarium, all under one roof and operated as integral parts of the same institution. When one enters the doors of the California Academy of Sciences he may, according to his interests, explore the wonders of the land on which he lives, probe the secrets of the sea around him, or contemplate the order and majesty of the starry heavens above.

Alexander F. and May T. Morrison

Alexander F. Morrison, a distinguished San Francisco attorney, became a member of the California Academy of Sciences in 1906, and a patron in 1916, and actively interested himself in the Academy till his death in 1921. Subsequently his widow, May Treat Morrison, became a member of the Academy and was elected a Trustee in 1926, a responsibility which she accepted graciously and discharged ably for the remainder of her life.

On her death in 1939 she bequeathed most of her estate to philanthropic and educational purposes. One bequest was a sum of $150,000 to the California Academy of Sciences for the purpose of erecting an auditorium as a memorial to her husband. She also left a larger sum to be dispensed for philanthropic purposes at the discretion of the executor of the estate, Mr. Edward Hohfeld, who had been Mr. Morrison's law partner.

Mr. Hohfeld, as stated above, offered to make $200,000 available for a planetarium to be named in honor of Mr. Morrison. After the necessary funds had been raised, the Academy's Trustees were faced with a perplexing question. They wished to honor Mrs. Morrison as well as her husband. Were they obligated to name both the planetarium and the auditorium after Mr. Morrison? Mr. Hohfeld affirmed as his legal opinion that a planetarium seating upwards of 500 persons came within the definition of an auditorium, and that in erecting the Alexander F. Morrison Planetarium the Academy's Trustees had discharged their obligations under Mrs. Morrison's bequest, and could name the auditorium after anybody they wished. The Trustees thereupon promptly voted to name the new auditorium after Mrs. Morrison.

One accordingly finds, in the Academy's new Hall of Science, the Alexander F. Morrison Planetarium and the May Treat Morrison Auditorium, fitting memorials to a husband and wife, two great and public-spirited citizens of San Francisco.

San Francisco's own planetarium

While the Morrison Planetarium was in the planning stage, a difficulty developed that few people had thought of: Where were we going to get a star projector? All of the previous planetariums, whether in Chicago, New York, Philadelphia, Munich, or Tokyo, had been made by the Carl Zeiss optical works in Jena, Germany. The Zeiss plant had fallen into Russian hands, and an inquiry to the New York office of Zeiss brought back the reply that they could not supply a planetarium projector then or in the foreseeable future.

Dr. Hanna and I talked the matter over. We looked at the optical shop that had been developed during the war. We had repaired range finders, sextants, azimuth circles, anti-aircraft gunsights, submarine periscopes. We had manufactured all of the missing or damaged parts, whether optical or mechanical. We had a group of experienced workers of proven competence. Why not build our own planetarium projector?

We made a quick trip to Los Angeles, spent several hours studying the Zeiss projector in the Griffith Planetarium, came back to San Francisco the next day and informed the Trustees that we could make one.

This announcement was received with mixed reactions. The Trustees felt pretty sure we knew what we were talking about; but on the other hand

they were naturally hesitant to put trust funds into an expensive project that was admittedly experimental, and furthermore without precedent in this country. Moreover, until the question of where the star projector was to come from had been resolved, the whole building project was in abeyance.

In this dilemma we invited as consultant Dr. Russell W. Porter, who had been associated over a period of years with the designing and installation of the 200-inch telescope at Palomar. Dr. Porter came to San Francisco and spent a week in our shop, going over plans and talking to key personnel. At the end of that period, on March 23, 1948, at a small luncheon at the Stock Exchange Club, Dr. Porter informed the Trustees that it was his considered opinion that we could build a star projector equal to or better than the Zeiss. That did it. We were authorized to proceed, and work on the projector began on July 1.

Dr. Porter was retained as a consultant on the design of the planetarium, but unfortunately he died a few months later, after having made only two or three preliminary sketches. His death was a great loss to the project, for Dr. Porter was a fine designer and draftsman with an understanding of both optics and mechanics (see page 35).

After his death the designing proceeded along somewhat unorthodox and strictly empirical lines, but nevertheless it proceeded. Plans were worked out in shop conferences, at the lathe and milling machine. The "working drawings" were frequently pencil sketches on the back of an envelope; and the detailed drawings, of which we have a complete set, were in most cases made *after* the various parts had been machined, tried out, and found to work.

At shop conferences everybody had his say. No idea was too unusual or revolutionary to receive thoughtful consideration. Several working models were constructed and experimented with before a final plan was arrived at. But Dr. Hanna and I are agreed that, more than any other person, Albert S. Getten is responsible for the over-all design of the star projector, as well as for the driving mechanism and the intricate gear trains; and that Alvin C. Gundred and George Bunton are responsible for the electrical installations, including forty circuits that go into the projector through slip rings, four miles of wiring, and the complicated electrical controls. Leon Salanave computed, for the star plates, the position of every star visible to the naked eye, and checked the courses of the planets. Frances Greeby, with infinite care and patience, put every star in its place – working on the star plates under a specially constructed microscope. Dr. Hanna himself devised the unique method of making the star plates (described elsewhere in this issue), and built the microscope that Mrs. Greeby used! Raymond Greeby and Fred Lehmann did much of the precise machine work on the projector. Dan Parsons and Robert P. Depster ground most of the lenses. Herbert Jow made the careful drawings, from which any part of the projector can be duplicated if needed.

As a matter of fact, the undertaking proved greater than any of us had contemplated. We thought it could easily be completed in two years, at a cost of around $75,000. Actually it has taken more than four years, and has cost $140,000. It would have cost much more except for the fine coöperation of numerous San Francisco firms and individuals who have taken an interest in the project and have supplied goods and services either free or at a nominal cost.

Special mention should be made of assistance rendered by the U. S. Air Force, the U. S. Naval shipyards at San Francisco and Mare Island, the State Educational Agency for Surplus Property, and by General Electric, Westinghouse, Pacific Telephone and Telegraph Company, Graybar Electric Company, Standard Oil Company of California, Pacific Gas and Electric Company, and Bethlehem Pacific Shipbuilding Corporation.

What could a shipyard do for a planetarium? It was Bethlehem that delicately machined the 40-inch, half-ton castings for the main assembly, and that made the steel base that supports the 5,000-pound projector nine feet from the floor. These were the only parts of the job that were too big for the Academy's shop to handle.

In the design of the projector the basic features of the Zeiss instrument have been incorporated but with numerous modifications. It was Dr. Walter Bauersfeld of the Zeiss concern who principally designed the Zeiss planetarium, and he deserves great credit for his achievement. If we had been able to obtain detailed plans and specifications of the Zeiss instrument we would have been likely to follow them rather closely. As it was, we knew only in a general way how the Zeiss projector worked, so we set out to design the best possible instrument to do the same things. The result has been to effect a number of improvements.

This is the first planetarium that can be operated entirely automatically. While it is the intention in general to have "live" planetarium demonstrations, if the lecturer is suddenly called away by some emergency, he can flick a switch and a tape recording will take over, giving the lecture, dimming the house lights, turning on the stars, putting the planets through their proper motions in perfect synchronization with the lecture, finally bringing the daybreak and sunrise, then turning on the house lights, thanking people for listening, and inviting them to come again. Actually of course we will never leave the planetarium unattended while a show is in progress; but if a lecturer develops a bad throat the tape will come in handy.

The automatic feature is provided by a telephone-type switchboard which can be plugged in to accomplish, a stepping relay, 250 operations in succession on cue from the tape, the cue being provided by bits of foil on the back of the tape which complete an electric circuit.

The Academy of Sciences projector is quieter in operation than earlier instruments. The hemispheres containing the star plates have been brought closer to the center, giving a better distribution of weight and improving the appearance. The planet projectors, which are light in construction, have been put at the two ends of the instrument, instead of at the "waist" as in the Zeiss design. The "eyelids" which cut off the light of the stars when they reach the horizon are more positive in operation. The moon is not just a round white disc but an actual photograph of the moon projected on the dome. The stars themselves give a greater illusion of reality.

San Francisco's Morrison Planetarium has been from its very inception a community undertaking. The funds came from citizens in all walks of life, contributing according to their means. Many contributions were of five and ten dollars, and some as small as two. When a proposal was offered to give large donors special recognition, the Trustees opposed it, stating that a two-dollar contribution might mean as much to the person who gave it as a two thousand dollar contribution would mean to someone else.

As a result of this fine community spirit, San Francisco has its planetarium, conceived, designed and built here. And San Franciscans can rest assured that this, the first major planetarium to be made entirely in America, is not excelled by any other in the world. **END**

The bronze bust of Alexander F. Morrison and the memorial plaque mark the main entrance to the Planetarium chamber from the Hall of Astronomy.

FIGURE 1

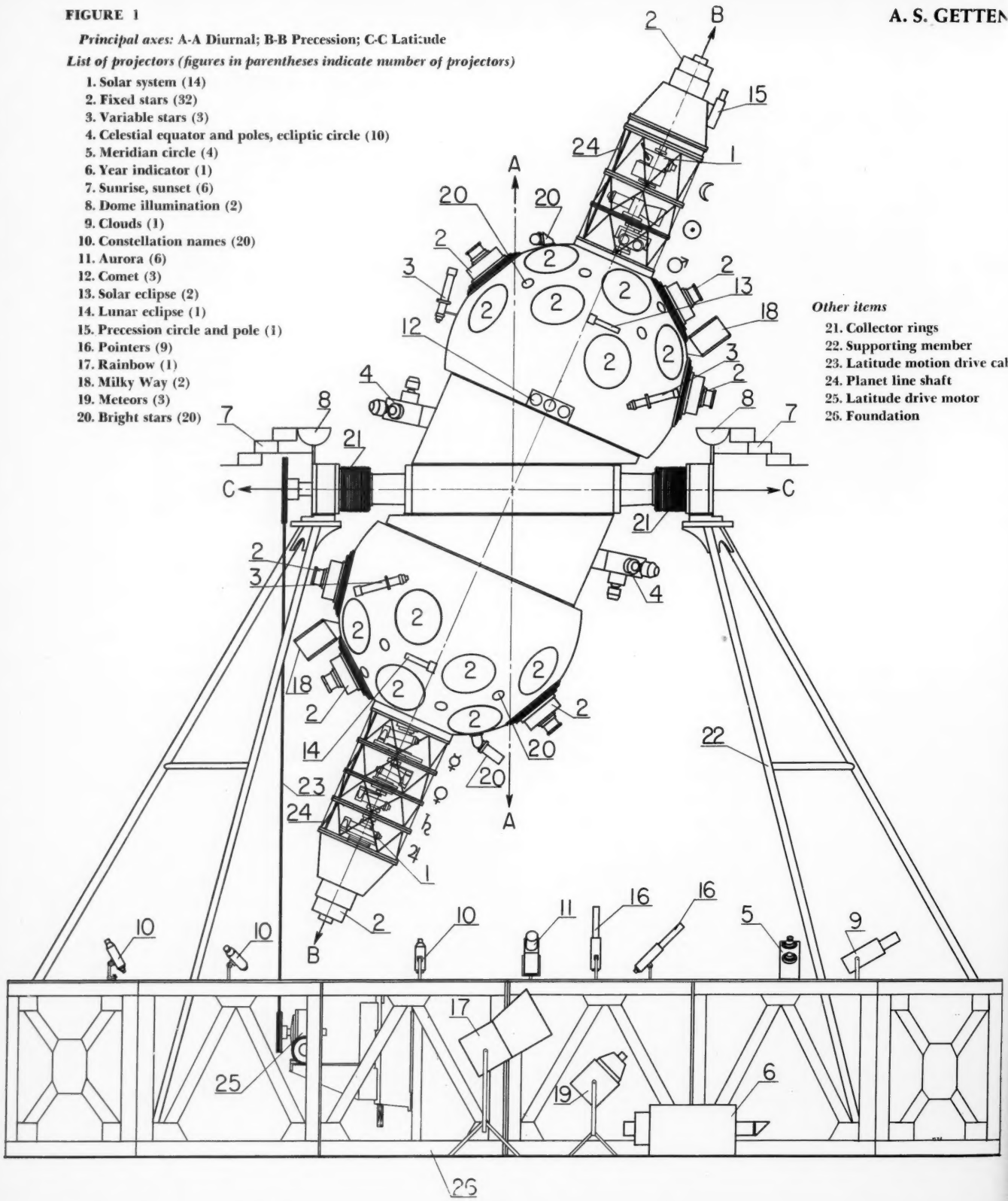
Principal axes: A-A Diurnal; B-B Precession; C-C Latitude

List of projectors (figures in parentheses indicate number of projectors)

1. Solar system (14)
2. Fixed stars (32)
3. Variable stars (3)
4. Celestial equator and poles, ecliptic circle (10)
5. Meridian circle (4)
6. Year indicator (1)
7. Sunrise, sunset (6)
8. Dome illumination (2)
9. Clouds (1)
10. Constellation names (20)
11. Aurora (6)
12. Comet (3)
13. Solar eclipse (2)
14. Lunar eclipse (1)
15. Precession circle and pole (1)
16. Pointers (9)
17. Rainbow (1)
18. Milky Way (2)
19. Meteors (3)
20. Bright stars (20)

Other items

21. Collector rings
22. Supporting member
23. Latitude motion drive cable
24. Planet line shaft
25. Latitude drive motor
26. Foundation



The chief designer of the world's newest major planetarium projector explains the theory and the intricate mechanics of gear trains and electrical and optical devices behind our heavenly drama

GEARED TO THE STARS

LIKE OTHER major optical planetaria, the Academy instrument is a complex device which can reproduce, by projection, the various and intricate celestial phenomena on the inner surface of a hemispherical dome. The purpose of these instruments is to portray the starry sky as it is seen from any latitude on the earth as well as the positions and apparent motions of the sun, moon, and visible planets at any period in any century. They demonstrate, moreover, the daily rotation of the earth on its axis and the slow precessional swing of the poles. Figure 1 shows the Academy instrument as essentially a multiple projector – an aggregation of projection systems each of which contributes a part of the whole picture.

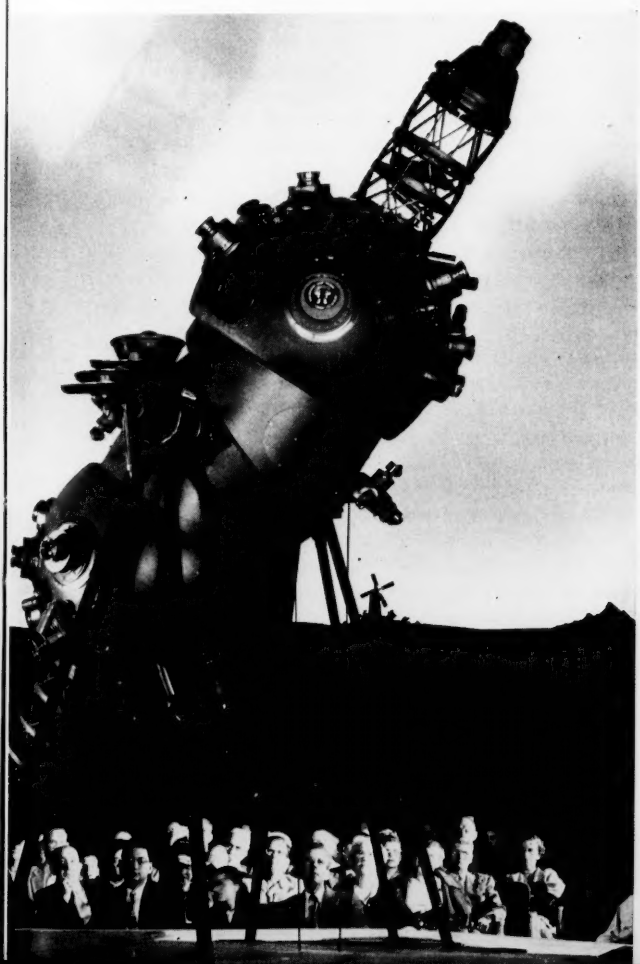
In presenting the fixed stars, the combined coverage of thirty-two of these separate projectors is required. Each unit projects a small section of the sky on the dome – an area of stars which is so shaped and oriented with other areas that all fit together to become a continuous whole – a mosaic of geometric figures.

The star projectors (figs. 1 and 2) are mounted on two large ball-shaped castings in groups of 16 – the individual members being clustered around centrally located 750-watt lamps and receiving their illumination therefrom. (It should be explained that two of the projectors, having been displaced by the planet cages, are supported on the cage ends. This relocation in no way affects the geometric arrangement of projected star fields since these two optical systems are merely moved outward along their axes.)

These 32 star projectors are complete optical units. Each is equipped with a condenser system for gathering light, a star plate (a very thin metal coating perforated with holes of different sizes which have been positioned to agree with the stars in an area of the sky), and a lens to project images of these holes. These are the stars that are seen on the planetarium dome. The position of each perforation in the plate has been carefully calculated to allow for certain distortions of projection and, more important, for a parallactic displacement that enters because many of the projectors are not centered; i.e., their optical axes are not coincident with radii of the dome. The size of hole in the plate determines, of course, the degree of brightness or magnitude of the simulated star.

When adopting this method of controlling star brightness we felt that the images should not be of excessive size. We therefore set, as an arbitrary limit, nine-tenths of an inch as our greatest projected star diameter. Rather than exceed this diameter, we provided a separate projector for each of the twenty brightest stars. These twenty units were designed to have optical characteristics capable of producing the necessary brightness without increasing the image size (figures 1 and 2).

In this way some 3,800 stars are shown ranging from the barely visible +5.8 magnitude to the brilliant Sirius magnitude −1.6. Three typical variable stars – Algol, Mira and delta Cephei – are projected by means of three rheostat-controlled units (3). Thus their brightness can be varied at will. Because stars below the horizon must not be seen, special occulting shutters are provided for all projectors. These devices automat-



When this photograph was taken, the moon projector had not yet been installed in its cage (24 in the diagram opposite). (Moss)

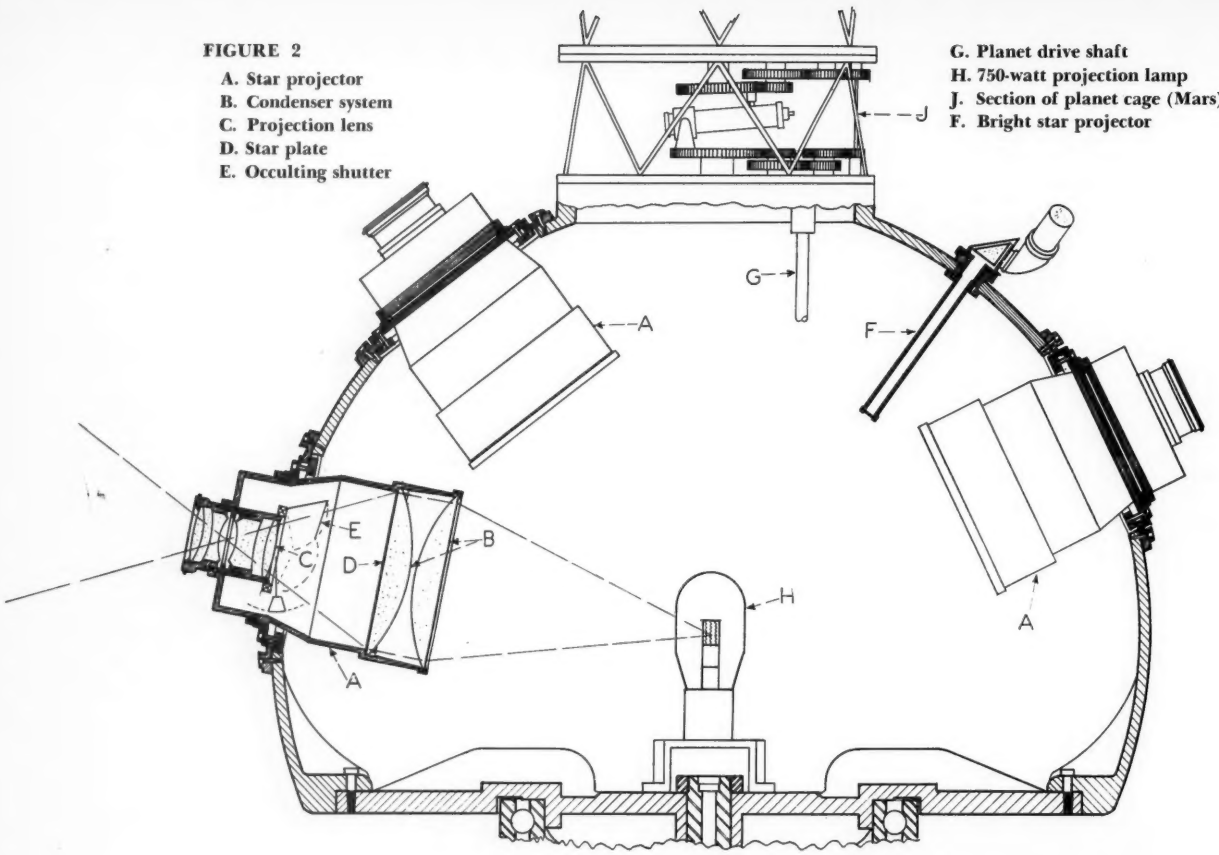


FIGURE 2

A. Star projector
B. Condenser system
C. Projection lens
D. Star plate
E. Occulting shutter
G. Planet drive shaft
H. 750-watt projection lamp
J. Section of planet cage (Mars)
F. Bright star projector

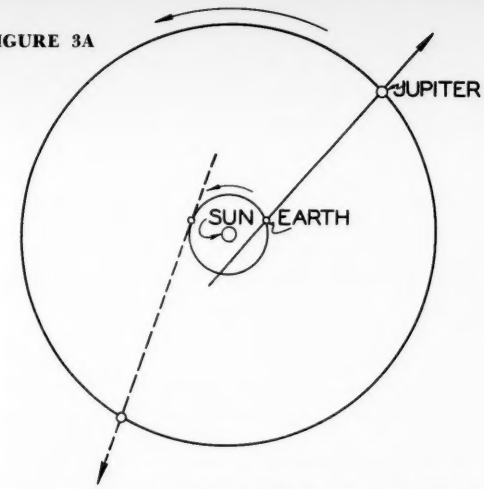
ically cut off the images as the horizontal plane is reached.

The star plates used in the Academy instrument are perhaps unique and represent much painstaking work. As was indicated earlier, a star plate is essentially a thin opaque material with holes in it of different diameters which have been located according to a definite pattern. Drilling or punching holes in a thin sheet of metal would seem to be the obvious way of making one. But why could not a thin opaque coating of aluminum be deposited, by the evaporation process, on a flat surface of glass in such a way that interruptions or holes in the coating occur at the predetermined positions? If the glass were placed horizontally with a sprinkling of small particles – say grains of sand – on its flat surface and if the aluminum were evaporated from above the glass, each grain would act as a mask or shield and prevent the metal coating from being deposited in that particular area. The resulting hole would be the size and shape of the sand grain within close limits.

Carborundum crystals were found to be satisfactory for this purpose and were obtainable in a variety of sizes. These tiny objects, some as small as .0015 inch, were individually placed on the plane surface of the front condenser lenses with the help of a crossline-equipped traversing microscope, its movement being controlled by two micrometer lead screws placed at right angles to each other. Since the coördinates of each corrected star position were known, the task became relatively simple, albeit laborious and time consuming. The projected images of these perforations in the metal coating are not circles, obviously, but are as irregular in shape as the grains themselves. It is possible that the illusion of a starry sky is helped thereby, as regular geometric images are not suggested. Dust in the air caused some difficulty as it settled continuously on the glass during the preparation of the plates and produced many hundreds of unwanted stars. A method of overcoming this was finally worked out and the celestial intruders eliminated. (See articles following, by Leon Salanave and Frances Greeby.)

The Milky Way is portrayed as a cloudy or hazy band of light across the sky – a shadowgraph produced by the passage of light from a concentrated central source through a specially prepared film wrapped around a double-walled cylindrical glass vessel. The space between these walls is half filled with mercury;

FIGURE 3A



the surface, always level, cuts off any portion of light below the horizon. Two of these units (18) are required to complete the full circular band of light.

It seems hardly necessary to add that all projectors, individually adjustable, must be accurately oriented and aligned not only with regard to each other but with the three principal axes of the instrument.

The members of the solar system, unlike the fixed stars, are relatively close to the earth and their individual movements can be discerned. Seven of these bodies are visible to the eye – the sun, moon, and the planets Mercury, Venus, Mars, Jupiter, and Saturn.

A number of centuries ago these objects, the planets especially, were little understood. They obviously moved about in the sky since their positions with regard to the stars changed continually. But their behavior was puzzling. Some planets were never far from the sun while others might be found in any part of the sky within a narrow zone. All, however, could be seen at one time or another to reverse their forward or easterly motions and move for a period in a westerly direction. Since it was assumed in ancient times that the planets revolved around the earth in simple circular paths it became necessary to invent intricate orbits involving epicycles in the attempt to explain these perplexing retrograde motions. Apollonius and later Ptolemy are given credit for this ingenious system. But it was not until Copernicus suggested, and Bradley later proved, that the planets revolve not around the earth but around the sun that their intricate apparent motions were understood.

Figure 3A, which shows the orbits of the earth and a typical outer planet–Jupiter–will perhaps make this clear. It must be evident that because Jupiter and the earth revolve around the sun at different velocities their relative positions are constantly changing. As seen from the earth Jupiter will appear at times to be moving eastward (forward in its orbit). The earth, because of its greater speed, will occasionally overtake and pass the outer planet, and during these periods Jupiter will appear to reverse its direction and move westward. It is clear that the apparent path of this planet or of any planet is a resultant; i.e., a compounding of two motions, its own and the earth's.

An ingenious method of generating mechanically these complex movements is found in the Carl Zeiss planetarium projector. The Academy instrument makes use of these principles.

Referring again to figure 3A, the arrow shown connecting the earth and Jupiter represents a beam of light from an optical system which is projecting an image of Jupiter on the dome. As the two planets move

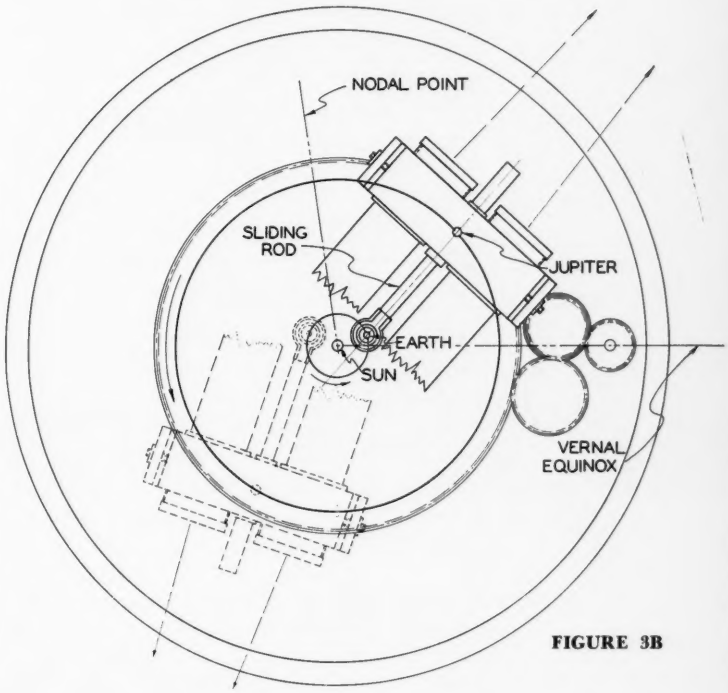


FIGURE 3B

in their respective orbits at their correct relative speeds, the beam of light which must at all times pass through these two moving points because of a mechanical linkage (figures 3B and 3C) automatically

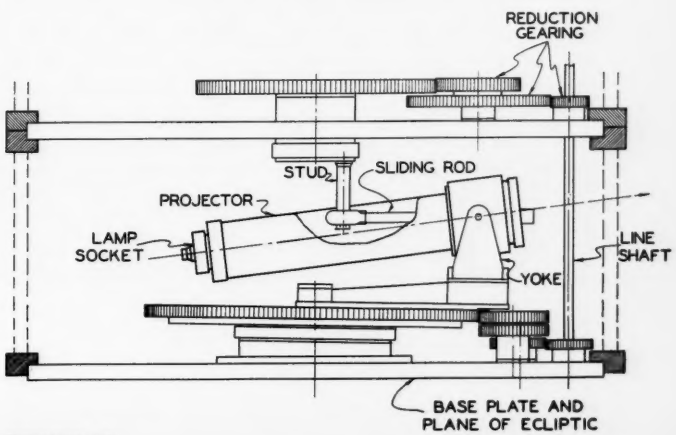
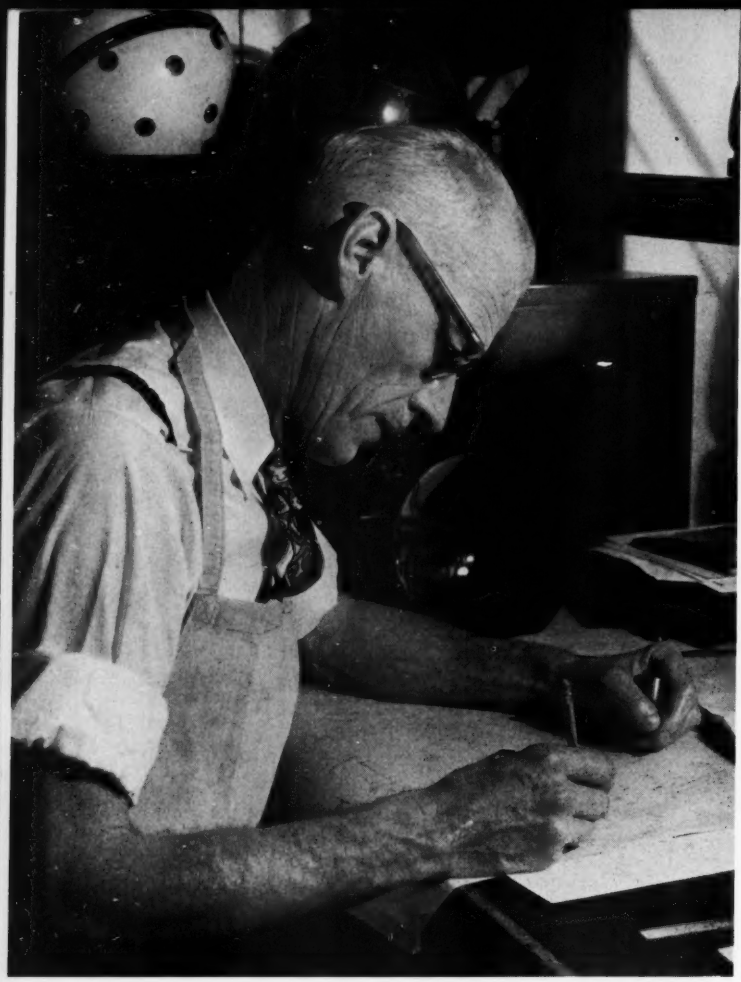


FIGURE 3C



The author at his work bench in the Academy Shop. (Woody Williams)

traces a path on the dome which is a resultant of the two motions. Obviously we have made use of a scale model of the earth–Jupiter system. Without question the correct end result (the moving image on the dome) is dependent on the accuracy of this miniature model. All possible orbital data must be incorporated and the greatest care shown in its construction.

By similar means the apparent motions of Mercury, Venus, Mars, and Saturn are shown.

The seven solar system projectors are housed in the two cage structures shown in figure 1. In all cases they are arranged in pairs, the two halves projecting identical images which are made to superimpose on the dome. In this way the effects of obstruction of the cage struts are minimized. Each projector is driven, through suitable reduction gearing, by a common line shaft running the length of each cage. Each projector is equipped with a mercury switch which turns off its light as the horizon is reached.

The solar projector, relatively simple in design, is made to rotate once in a planetarium year. To insure its appearance at correct celestial longitudes the variation of angular velocity must be reproduced.

The lunar projector, on the other hand, is one of great complexity. It rotates once in a sidereal month in a plane which is inclined 5° to the plane of the ecliptic. This orbital plane, however, is not fixed but is itself slowly regressing so that the line of nodes (the intersection of the two planes) completes a revolution in approximately 18 years, 7 months. The various lunar phases are shown as recurring every synodic month. In presenting the moon, an actual photograph of the lunar disk is projected in the planetarium sky.

Both solar and lunar projectors are equipped with separate rheostats so that the brilliancy of their images can be controlled.

The plane of the ecliptic, represented on the sky by a great circle, passes through the mechanical center of the planetarium instrument and also through the geometric center of the dome. Because the solar system projectors are located either above or below this plane, each must be given a certain fixed inclination in order that its image may bear a correct relationship; i.e., the sun must travel in this plane while the moon and planets must cross it when reaching their respective nodal positions.

There are four distinct types of motion in the planetarium instrument: that for change of latitude, the daily motion, the precessional motion, and the yearly motion. The first of these is independent of the others. An electric motor drives the projector about axis C-C (figure 1) which lies in a horizontal east-west position. This results in a change in the inclination of the polar axis A-A and a consequent change in the appearance of the sky. Since the horizontal axis is capable of moving through a full circle it is possible to incline the polar axis by any amount and show the sky as it is seen from any latitude on earth. The time required for this 360 degree swing is 4.5 minutes.

Movement about axis A-A causes the entire sky to circle about the celestial poles thereby demonstrating the daily rotation of the earth. The motor powering this motion is variable in speed, and it is located within the body of the instrument.

The third motion, the precession of the equinoxes, is caused in nature largely by the moon's gravitational pull on the earth's equatorial bulge. It is manifested as a slow circling of the celestial poles about fixed points – the ecliptic poles. While this celestial phenomenon requires very nearly 26,000 years for its completion, the planetarium instrument demonstrates it in 3.5 minutes by a motor-driven revolution about axis B-B.

The fourth, or yearly motion, has to do with the combined movements of all of the solar system projectors. These seven units, interlocked through reduction gearing, may be run either forward or backward. To follow this passage of time a special device (6)

which has been synchronized with the sun mechanism projects the date in years on the dome.

The Academy planetarium makes use of some 70 auxiliary projectors whose functions range from the educational to the esthetic. Figure 1 shows their locations.

There are two sets of projectors (4) which show the principal astronomical reference circles. These, the ecliptic and celestial equator, are projected as great circles on the dome, the former being graduated in daily positions of the sun and the latter graduated to indicate right ascension. The position of the north celestial pole is shown also.

The meridian projectors (5) are mounted on the fixed base of the instrument. Their function is to project a line graduated in degrees from north to south horizons through the zenith. The precessional unit (15) is located at the north end of the instrument and indicates the position of the ecliptic pole as well as the circle in the sky described by the earth's pole of rotation. It is graduated in 1,000-year periods of time.

Both solar and lunar eclipses are demonstrated by means of projectors (13 and 14). In one case the sun's disk is slowly eclipsed by the moon and in the other a simulated earth's shadow gradually obscures the lunar disk.

A projector (12) geared into the yearly drive will show a typical comet as it first appears faintly among the stars, as it approaches the sun gaining in brilliance and developing the characteristic tail, then as it rounds that body, and finally as it speeds into outer space becoming fainter and disappearing.

A striking display of meteor trails in the sky can be produced by a mechanically driven device (19) consisting of several slotted rotating disks. And finally, the names of the principal constellations and their outlines, as well as special objects such as nebulae, prominent stars, etc., can be shown and indicated by the use of some twenty-nine separate projectors (10 and 16) mounted on the structural members. The remaining sixteen projectors (7, 8, 9, 11, 17) create certain colorful lighting effects. By the discreet use of the apparatus the daylight is slowly dimmed and a sunset is suggested, to be followed by twilight and the first appearance of the stars. Striking cloud patterns, a rainbow, or the aurora may be shown. These optical devices offer many possible combinations and may greatly enhance the dramatic and esthetic side of a lecture.

The regimenting and precise control of this aggregation of projectors calls for a great deal of electrical equipment. Because the Academy planetarium was planned to be operative either by the manipulation of control switches (the conventional method in all planetaria) or by an automatic means, relays are used throughout in all circuits. In the first case the relays are controlled by small telephone type switches located on panels in a console at which the lecturer stands. These he operates according to the requirements of his lecture. In the other case the relays are controlled by an electrical stepping device which, with associate apparatus, has been pre-set to run through the planned operations and is in turn actuated by a sound tape delivering the lecture. This equipment, necessarily complicated, is installed in a separate room adjacent to the planetarium theater, and from it run the many required circuits, some to the console and others to the planetarium instrument, 40 being brought into the moving parts through three sets of collector rings and brushes. Sixty enter junction boxes on the foundation to be distributed to the numerous fixed projectors.

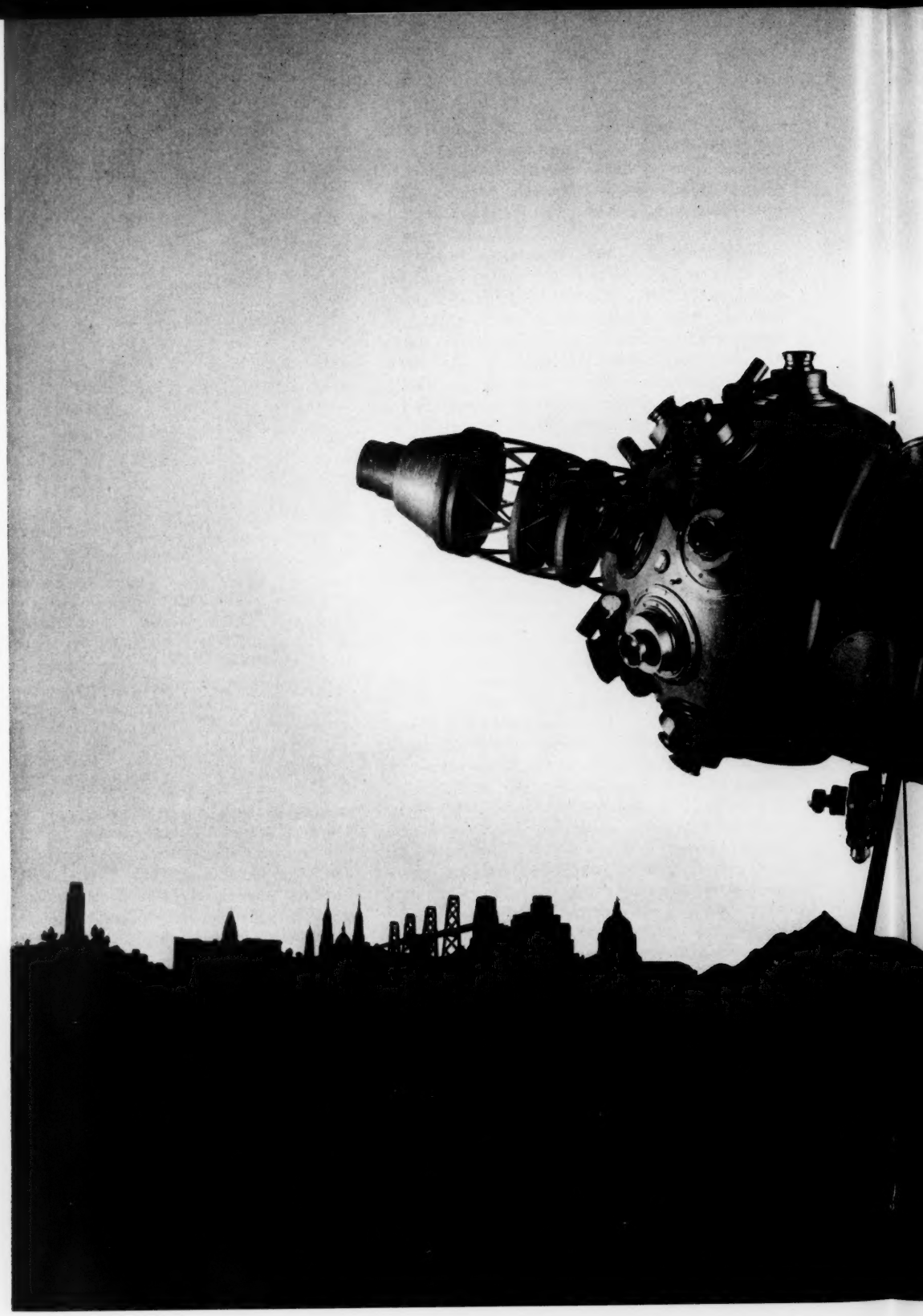
A feature that greatly increases the versatility of the Academy instrument is the use of variable speed in the electric driving motors that produce the effect of daily and yearly motion. It is possible to set the motion to whatever rate suits the occasion. A day can be made to pass in as short a time as 1.3 minutes or as long as 25 minutes and a year between the range of 24 seconds and 6.8 minutes. It is possible, by the use of differential gearing, to interconnect the two motions so that the operation of the daily carries with it the proportionate annual motion. Since these motors can be operated in either direction the audience can be transported as easily into the past as into the future.

The sound system offers interesting possibilities. Thirteen loud speakers have been placed within the theatre. Twelve are spaced equally around the room near the horizon and behind the perforated dome, and the thirteenth is directly overhead. Controls are provided for each speaker so that the sound can be made to come from any one or any combination of speakers. Many novel sound effects are thus possible.

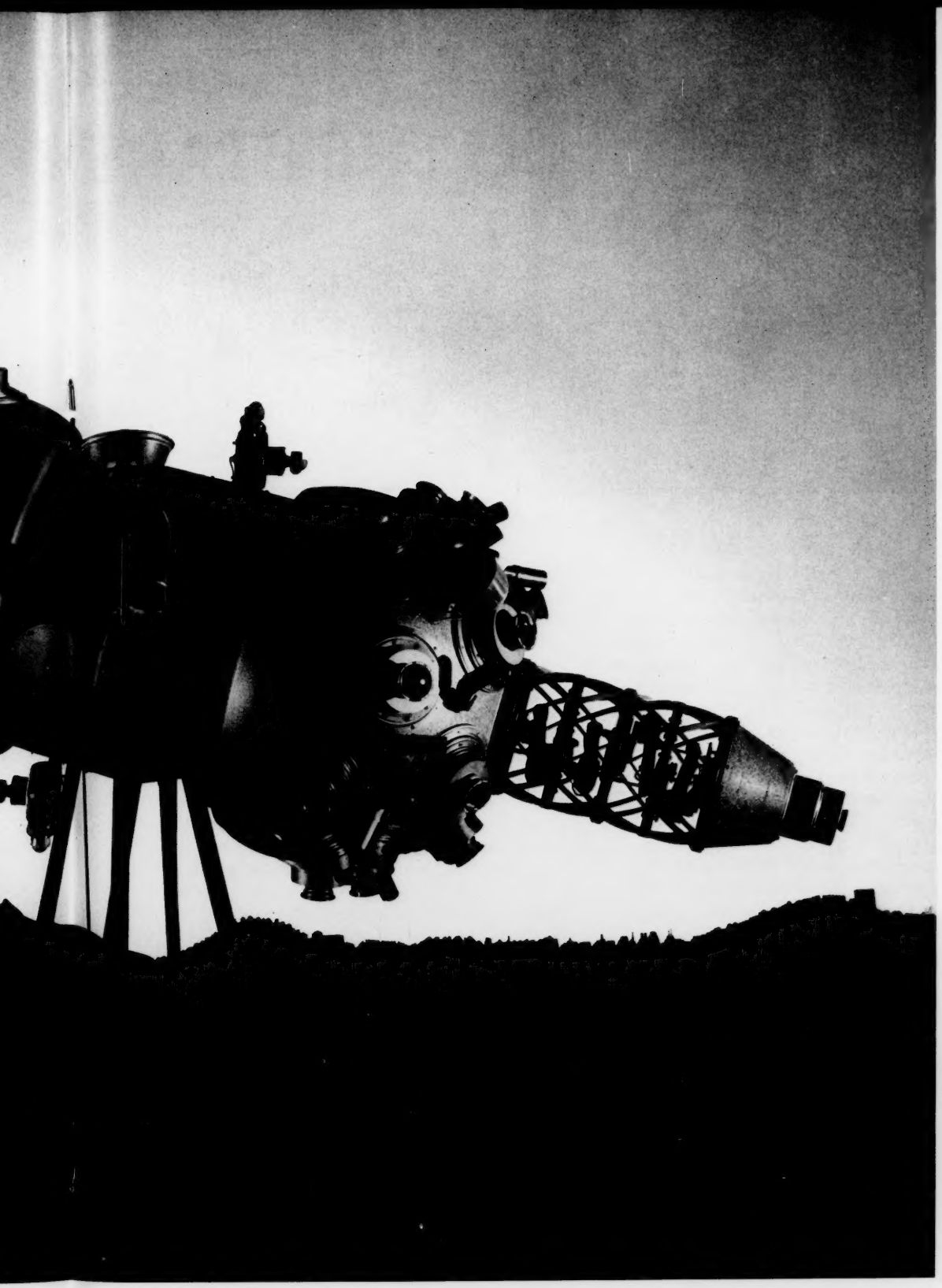
To the reader who has ventured this far, the following statistical information will be of interest:

Diameter of dome—65 feet.
Height of horizon above floor—9 feet.
Total length of instrument—13 feet.
Total weight—8,000 pounds.
Diameter of hemispheres—40 inches.
Total number of separate projectors—141.
Lenses used in projecting stars—30 Aero-Ektar f:2.5, 7″ focus; 2 Ross f:4.0, 5″ focus.
Total number of lenses of all descriptions—321.
Total number of ball bearings—304.
Total number of gears—158.
Total number of relay switches—220.
Total length of wiring—4 miles.

These are the ingredients for a planetarium show, a production which brings before our eyes the beauty and order of the universe. END



The Alexander F. Morrison Planetarium a



etarium at the California Academy of Sciences

PUTTING THE STARS

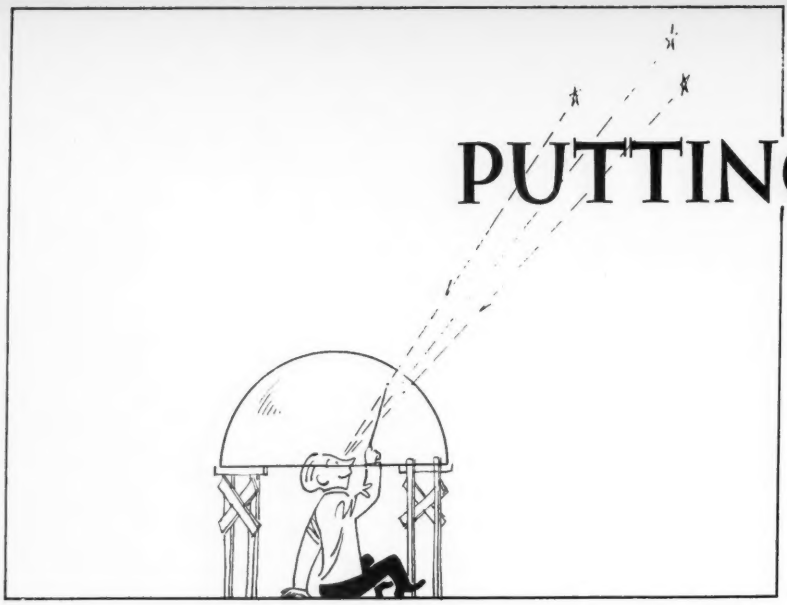


FIGURE 1. (Drawings by Frank Rinna)

HOW WOULD YOU construct a starry sky for indoor exhibition? To visualize the problem, imagine yourself located at night on a perfectly flat stretch of desert. The sky appears to be an inverted, star-studded bowl. You notice, among other things, three stars in a group as illustrated in figure 1.

Now take a clear plastic bowl in the shape of a hemisphere about three feet in diameter, and support it over your head so that your right eye is at the center. Make three marks on the inside of the bowl where the three lines of sight appear to pass from the sky through the bowl and into your eye.

Let us now take some black paint and cover the inside surface of the bowl except at the three places previously marked. Here we leave clear spots, each about the diameter of a pin-head.

Figure 2 shows the next step in our planetarium-making enterprise. Inside a large dome, say 50 feet in diameter and white-surfaced like a movie screen, we place a bright point source of light. When the blackened hemisphere with the three clear openings is turned over the lamp, behold — the pattern of the three stars shows *by projection* on the inside surface of the large dome! You can imagine the stars as they were seen in the heavens although, to be sure, the off-center position from which you must view the projection will produce some distortion. But if the dome is large and you sit near its center, the effect will be realistic and convincing.

The principle just described can be used to construct a simple star projector for a planetarium. The stars visible to the unaided eye have all been located by precise astronomical observations and catalogued in a system which fixes each star according to its place on the sky. The scheme used corresponds to the system of latitude and longitude commonly used to locate places on the earth.[1]* For each star there is also a measure of its brightness.[2] Therefore, it is necessary merely to procure a hollow globe upon which the star positions have been mapped, then drill holes of assorted sizes corresponding to the different star brightnesses to be represented. When a small bright lamp is placed in the center of this globe and the whole apparatus is enclosed under a darkened dome, a fairly realis-

*Numbers refer to notes at end of this article.

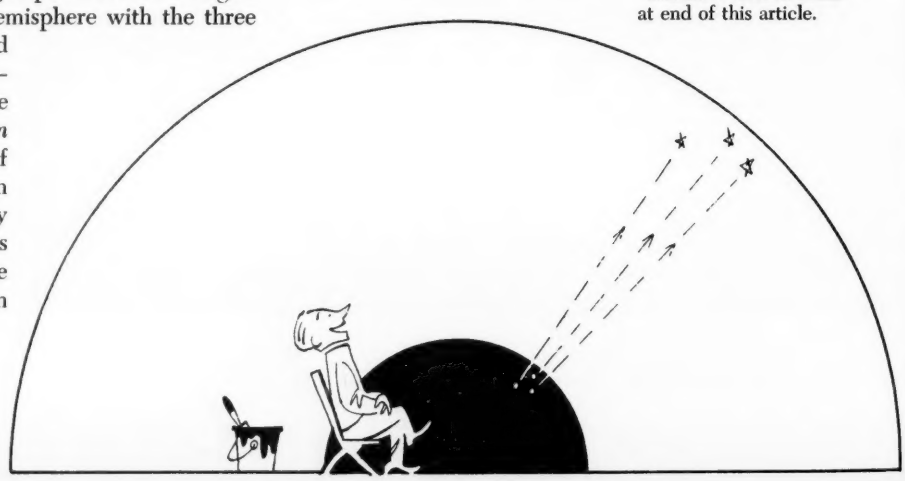


FIGURE 2.

LEON E. SALANAVE

IN THE SKY

It's a simple concept—but look at the array of computing machines and mathematical wizardry it took to place the stars in celestial order within the Planetarium dome!

tic representation of the heavens can be produced. The greatest limitation of the pinhole projection is its lack of brilliance; it is impossible to produce sharp bright stars in a large dome capable of seating an audience of several hundred persons. To attain the desired brilliance it is necessary to use a projection system in which a *lens* gathers the illumination from each pinhole and focuses it sharply on the dome.

The introduction of lenses requires that the planetarium sky be projected in numerous sections, as a mosaic of star fields thrown on a screen like so many lantern slides. The fact that lenses are designed to project a flat surface and in so doing invert the image, gives rise to complicated distortions when it is our desire to produce a picture of the sky that conforms smoothly to the curved inner surface of a dome.

In planning the star projectors for the Morrison Planetarium we decided to incorporate the same basic idea used in the Zeiss instrument; i.e., the star sphere is reduced approximately to the surface of a geometric solid bounded by 32 plane faces. To produce this figure we start with an object known as an *icosahedron,* which has 20 equilateral triangular faces and 12 corners, or vertices. When this figure is modified by cutting off sections at each of the twelve vertices, the desired 32-faced pattern is obtained. It consists of 12 pentagons and 20 hexagons.

In designing the Academy projector it was necessary to take the ideal pattern of 32 plates arranged at equal distances from a central projection lamp and break it down into two sets of 15 each, each set having its own central lamp. (Refer to figure 2 of Mr. Getten's article.) The two remaining plates had to be set on the ends of the planet cages.

The large projection lamps are displaced 21.5 inches from the center of the 65-foot dome; it is therefore clear that, as the lenses are projecting off-center, a certain amount of distortion will be produced. The remedy is to displace the plates in their projectors by a calculated amount which will locate the stars in their proper places on the dome.

One of the big jobs in the building of our star projector involved sorting out the stars to be assigned to each of the 32 fields, and then computing the stars' positions thereon. The vast amount of labor involved in this work was carried out on International Business Machines sorting and calculating devices in the Computing Laboratory, University of California, Berkeley.

In connection with the mathematical work, much valuable assistance was given by Dr. Leland E. Cunningham, associate professor of Astronomy, University of California, and Dr. Paul Morton, professor of electrical engineering in charge of the Computing Laboratory.

It was decided that stars of magnitude 5.79 could be taken as the faintest to project on the dome and still retain the desired impression of a star-filled sky. Stars as faint as magnitude 6.0, of which there are approximately 4,850, can be seen without optical aid by most people. Our limit of

The author, astronomer for the Morrison Planetarium, checks star positions on punch-cards against the star charts. (C.A.S. Photos — Moss Studios)

faintness called for the placement of about 3,800 stars, approximately 1,000 less than the theoretical limit would require. A number of astronomers were consulted on this critical point, and all agreed that few, if any, observers take notice of these faint stars when they view the constellations. Thus, by adopting the lesser limit, a saving of more than 1,000 computations and locations on the star plates was effected – at no appreciable sacrifice in the splendor of the heavens. (It must be noted here that the *Milky Way,* which in nature represents the combined light of *millions of very faint stars,* is taken care of in the planetarium by a special projector and therefore does not depend upon the stars whose places had to be computed individually.)

One of the most extensive star catalogs at the disposal of astronomers is the Boss General Catalog of 33,342 stars. This tremendous collection of data has been compiled on punched cards by the Watson Computing Laboratories at Columbia University. We needed only a small part of this catalog's contents for the planetarium project, namely the positions and magnitudes of a mere 3,800 out of the 33,342 in the card file. At first glance, sorting out the stars appeared to be quite a task!

One of the most useful of the IBM devices for our work was a *collator.* This machine can read a specified number off a punched card and, according to instructions provided by a control mechanism, either select or reject the card into a receiving hopper. Our problem was to select cards (stars) for which the magnitude number was less than 5.80. Sorting four per second, the machine picked out the 3,800 cards from the deck of 33,342 in two and a third hours of running time.

Having sorted out the particular stars destined for our planetarium sky, we then had to transfer the essential information onto fresh cards which were to be used in subsequent computations. This was done by another mechanical and electrical wizard, a *reproducer.* Of the score of items tabulated on each star, we wanted only four: the *catalog number* (for identification purposes), *right ascension and declination* (for position on the sky), and *magnitude* (for stellar brightness). The control panel of an IBM reproducer was wired up so that the machine read off the required numbers and punched them into a new, clean card, one for each star. Original Boss catalog cards were fed into one hopper, new cards into another, and *presto* – the new cards came out punched with the desired information at the rate of 100 per minute.

Figure 3 is a photograph of the punched card for *Arcturus;* along the upper margin of the card are printed the numbers which constitute the data for this star.

2271 is the identification number of Arcturus in the list of planetarium stars – our "CAS" number.

19242 is the star's number in the Boss Catalog – also for identification purposes.

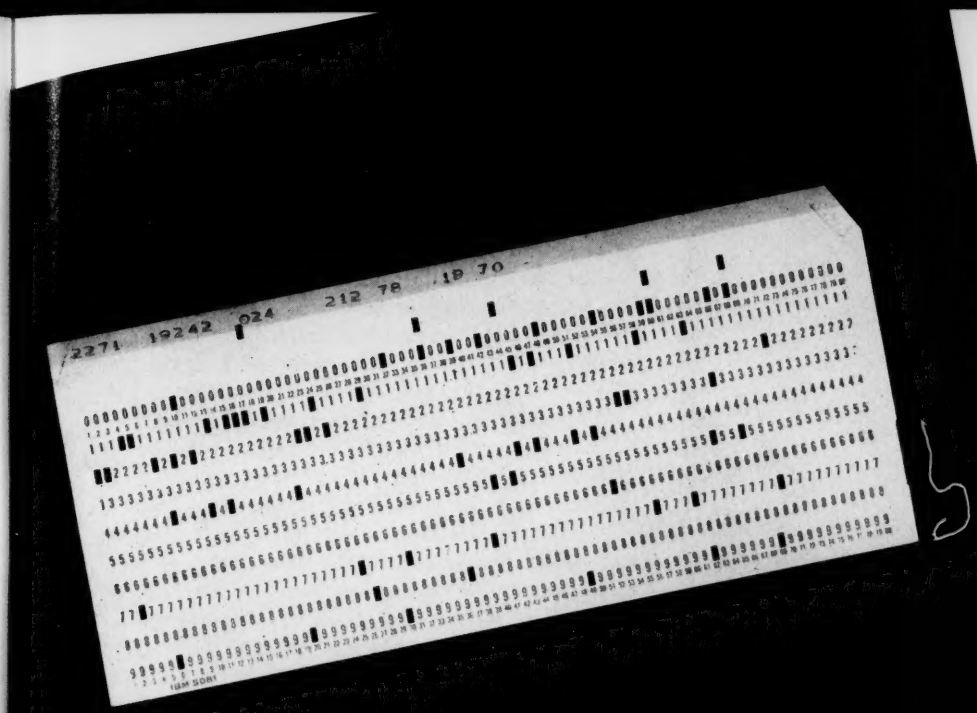
024 – actually read 0.24 – is the stellar magnitude or brightness number. Arcturus is one of the half dozen brightest stars in the heavens.

212 78 gives the degrees and hundredths of the right ascension.

19 70 gives the degrees and hundredths of the declination. This is taken to be positive (north of equator) unless preceded by the letter N, for negative value.

Having compiled the 3,800 data cards[3] and arranged them in order of their right ascension numbers, the next major problem we had to solve was that of sorting the stars out into their appropriate projection fields. The *collator* was used again. With appropriate wiring the collator can select or reject a card if a given number falls inside or outside of specified limits. Here it was a matter of selecting all the stars whose position numbers (i.e., coördinates of right ascension and declination) were within the extremes covered by each star projection plate. The sorting was accomplished by feeding a control card which carried the values of the extremes in declination into one hopper of the collator. Then, all the cards corresponding to stars whose right ascensions placed them within the particular field limits were fed into the other hopper, and the machine picked out those with suitable declinations. From these, *field data cards* were made in the *reproducer.*

Since some of the boundaries of the star plates unavoidably cut across the sky in directions that do not correspond to meridians and parallels, the deck of field data cards contained all the stars that could *possibly* go on the plate, but the sorting process did not tell which of the stars *actually* fell within the particular pentagon or hexagon that defined each field. It was therefore necessary to carry along into the final steps of the computing process many stars which, when plotted, proved to be just outside the bounds of one plate and therefore in a neighboring one.



← Fig. 3. IBM punch-card for the star Arcturus.

↓ Fig. 4. One of the 126 tabulation sheets for 6,200 punch-cards.

9036	5.16								
9037	5.78	3.238	4.883	2168	0.99340	-0.07224	-0.08984		
9038	4.93	3.412	5.256	2169	0.98941	-0.04992	-0.13778		
9039	3.44	3.938	6.127	2178	0.97006	0.01774	-0.24972		
9040	4.96	4.187	6.698	2179	0.95047	0.04976	-0.32317		
9041	4.92	2.203	1.738	2180	0.93620	-0.20525	0.31434		
9042	5.54	2.328	1.839	2186	0.94210	-0.18924	0.30141		
9043	5.65	3.739	5.132	2191	0.99261	-0.00778	-0.12188		
9044	5.62	3.296	3.955	2196	0.99746	-0.06483	0.02942		
9045	4.51	4.230	6.021	2200	0.97184	0.05525	-0.23612		
9046	4.28	3.657	4.267	2210	0.99979	-0.01644	-0.01066		
9047	5.06	3.777	4.368	2220	0.99971	-0.00294	-0.02361		
9048	4.96	3.493	3.680	2221	0.99714	-0.03950	0.06475		
9049	5.71	2.823	1.940	2225	0.95390	-0.12552	0.28849		
9050	5.30	3.772	4.055	2228	0.99985	-0.00337	0.01661		
9051	2.80	4.862	6.462	2231	0.95161	0.13656	-0.29277		
9052	5.18	3.792	3.977	2232	0.99964	-0.00107	0.02664		
9053	5.42	3.380	2.874	2235	0.98476	-0.05393	0.16836		
9054	4.34	3.731	3.515	2239	0.99628	-0.00869	0.08595		
9055	4.82	4.944	6.031	2242	0.96313	0.14702	-0.23743		
9056	4.90	3.878	2.934	2255	0.98728	0.01003	0.16066		
9057	5.54	5.234	5.768	2258	0.96427	0.18438	-0.20358		
9058	5.36	4.677	4.396	2263	0.99334	0.11272	-0.02722		
9059	0.24	4.964	4.743	2266	0.98827	0.13681	-0.07185		
9060	4.83	4.367	3.595	2271	0.99450	0.07294	0.07568		
9061	5.31	3.456	1.468	2279	0.94331	-0.04426	0.34906		
9062	5.24	4.829	4.320	2283	0.99122	0.13223	-0.01742		
9063	4.97	5.769	6.299	2282	0.93743	0.25305	-0.27188		
9064	5.11	4.678	3.955	2285	0.99329	0.11281	0.02947		
9065	5.74	5.229	4.932	2291	0.98023	0.18371	-0.08333		
9066	5.08	5.260	4.949	2293	0.97938	0.18770	-0.08546		
9067	5.36	5.412	5.157	2295	0.97191	0.20721	-0.12508		
9068	4.97	4.681	3.447	2299	0.98927	0.11321	0.09475		
9069	3.78	6.061	6.171	2302	0.93261	0.29065	-0.25541		
9070	4.48	4.180	2.016	2308	0.96230	0.04690	0.27841		
9071	4.94	4.270	2.002	2313	0.96123	0.06035	0.28043		
9072	3.86	5.313	3.557	2324	0.97945	0.19452	0.06779		
9073	5.03	5.460	3.913	2325	0.97741	0.21333	0.03488		
9074	5.63	5.826	4.605	2326	0.96637	0.26046	-0.05407		
9075	4.93	5.633	4.212	2327	0.97334	0.23563	-0.00360		
9076	5.54	4.719	2.282	2333	0.96505	0.11814	0.24444		
9077	4.59	6.449	5.520	2337	0.93436	0.34044	-0.17173		
9078	2.70	5.382	3.448	2338	0.97575	0.20336	0.09455		
9079	3.76	4.728	2.187	2339	0.96221	0.11925	0.25666		
9080	5.66	6.393	5.349	2340	0.93925	0.33331	-0.14969		
9081	5.05	4.768	1.910	2352	0.95305	0.12439	0.29232		
9082	5.50	6.853	5.854	2354	0.91283	0.39244	-0.21463		
9083	4.64	4.182	0.742	2357	0.91357	0.04906	0.44241		
9084	5.77	5.430	3.085	2358	0.96951	0.20952	0.14121		
9085	4.59	5.864	3.588	2369	0.96331	0.26782	0.07664		
		7.232	6.052	2372	0.89360	0.44109			

Arcturus

Sixty feet of IBM tabulations giving brightness and position for each of the 3,800 stars selected to appear in the Planetarium sky.

to nearly 6,200. In addition, the positions of 120 plate corners were tabulated in the same manner as stars so that the boundaries of each projection plate might be precisely determined.

Computations of the star places on the projection plates were carried out on the International Business Machines punch-card calculator, known fondly as "The 602-A" at the computing laboratory. The procedure was as follows:

For each of the 32 star fields there was a *master card* on which were punched the celestial coördinates of the field center.[4] Immediately following this card were the cards for all the stars previously sorted into that field, likewise carrying the celestial ccördinates. As soon as the master card passed into the computer, the data on that card were instantly read into a series of numerical storage devices, where they were retained throughout the computations for that field. Then, as each *detail card* (one per star) followed the master card into the machine the data it carried were read off by other storage units. Finally, the computer automatically combined the two sets of numerical data according to formulas fed into it through the wiring of its control panel.

The mathematical processes involved were nothing more than simple addition, subtraction, multiplication, and division of numbers expressed to five decimal places. Three separate runs of the

After each field was sorted it was necessary to return the data cards to the master deck, because some of them would turn up again on other fields. Again the collator was used, for this versatile machine can also *merge* (the opposite of *sort)* two decks of ordered cards into a single deck, retaining the same numerical sequence.

The process had to be carried out 32 times, once for each of the star fields. Each card in these decks was given a new number, corresponding to a *field number* for the star it represented — in order of right ascension across the extent of the field. Taking up again the example of the star *Arcturus,* it turned out that this star came up as No. 59 in Field 9; thus its code number became 09-059, while at the same time its identity as star No. 2271 on the planetarium sky was retained.

We started out the sorting process with 3,800 cards; the duplications in the final sorting were such that the total number of cards handled rose

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Dr. Paul Morton, in charge of the Computing Laboratory, and the author check numbers in the storage units of the IBM punch-card computer.

6,200 cards through the computer were required. Working on an average of twelve cards per minute, the 602-A performed a total of 18,000 additions and subtractions, 74,400 multiplications, and 6,200 divisions of five-figure numbers. Running time: twenty-six hours.

The final step in this long trail of number work was the tabulation of the results, so that each star might eventually be checked off and placed on the proper projection plate. For this job the IBM tabulator was used. This machine will print numbers and letters taken directly from each one of a stack of cards, according to directions wired into it by a control panel. Figure 4 shows one of the 126 sheets obtained in the tabulation of 6,200 cards. The star Arcturus, for example, is identified by its CAS No. 2271, in column 5, or its field number 9059, in column 1. Some of the other numbers shown have meanings which need not concern us here. However, columns 2, 3, and 4 are of interest in that they contain essentially the information needed to plot each star in the planetarium projector – as follows:

Column 2 gives the star's magnitude, to hundredths.

Column 3 gives the position of the star counting from the right edge of the field, in inches and thousandths.

Column 4 gives the position counting from the bottom of the field, given also in inches and thousandths.

As has been noted previously, these positions allow for the inversion of the images by the projection lens, as well as for the distortions produced by the lenses and off-center positions of the projectors in the dome.

When the 3,800 tabulations were complete, Mrs. Frances M. Greeby was ready to begin placing the stars in their proper positions on the star projectors. Star by star a sky was filled. END

Notes

1. This system of *celestial coördinates* is defined by two arcs measured on the sky: (a) *Declination*, measured in degrees north or south of the celestial equator, and (b) *Right Ascension*, measured eastward from the First Point of Aries (also known as the Vernal Equinox Point).

2. Apparent stellar brightness is measured by a system of magnitude numbers, in which "6" corresponds to the faintest stars seen by the unaided eye and "1," "0," or even negative values designate very bright stars. For example, Polaris has a magnitude of 2, Aldebaran's magnitude is 1, and that of Alpha Centauri is 0. Sirius, the brightest star in the sky, is fixed at magnitude *minus* 1.6.

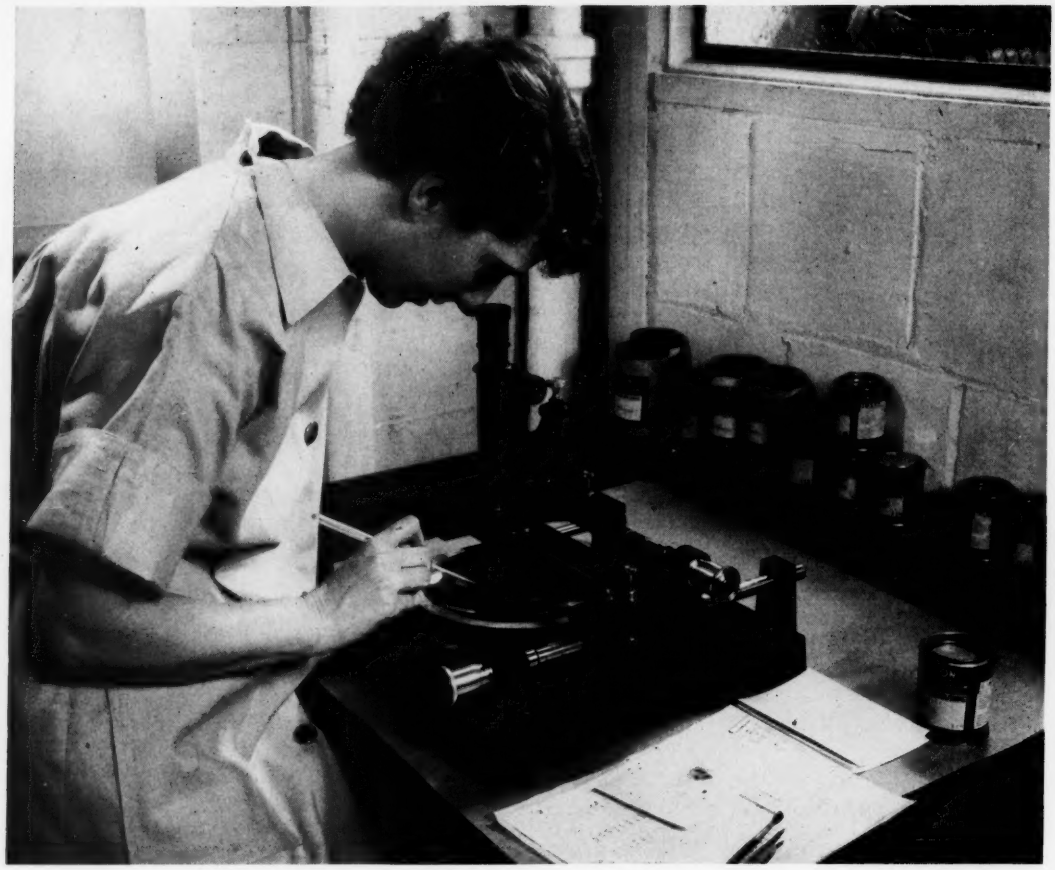
The mathematical relation between a star's magnitude, m, and the apparent intensity of its light, I, is expressed by the formula: $m = -2.5 \log_{10} I$.

The unit value of stellar light intensity is usually taken to be that of a star of magnitude zero. On this basis a star of the 6th magnitude has a light value of approximately .004; at the other extreme Sirius has a light value of 4.4 times a zero magnitude star. In constructing an accurate planetarium it would therefore be necessary to provide for a brightness range of 1,100 to one in the projected star images.

3. In addition to the stars obtained from the Boss Catalog, 27 naked eye nebulae and star clusters were included. These were destined to be located on the projection plates with the stars. This is a point of departure from the Zeiss planetarium in which all nebulae and clusters were provided by separate, special projectors.

4. More precisely, three *direction cosines* which are equivalent to two coördinate arcs on the celestial sphere. Because the axis of mechanical symmetry of the planetarium instrument is about the plane of the ecliptic rather than that of the equator, the direction cosines used in the last part of the computing procedure were expressed in the ecliptic – not the equator – system.

An IBM collator at the University of California Computing Laboratory sorts out the 3,800 stars from a total of 33,342 in the Boss Catalog. The author feeds a handful of cards into the hopper.



THE STARS THROUGH A MICROSCOPE

AS POINTED OUT in the preceding article, star plates in a planetarium projector consist of sheets of opaque material in which a large number of holes of assorted sizes have been placed so that light passing through them will be projected as starlike points on the planetarium dome.

After astronomical data and computations determined the placement of these holes and their relative sizes, the fabrication of the star plates remained – a difficult technical problem.

In other planetarium projectors these holes had been produced by punching them in thin copper foil only .002 inch thick. The punched holes were circular in shape. Consequently they produced circular discs for stars, quite unlike the seeming sharp points of real stars.

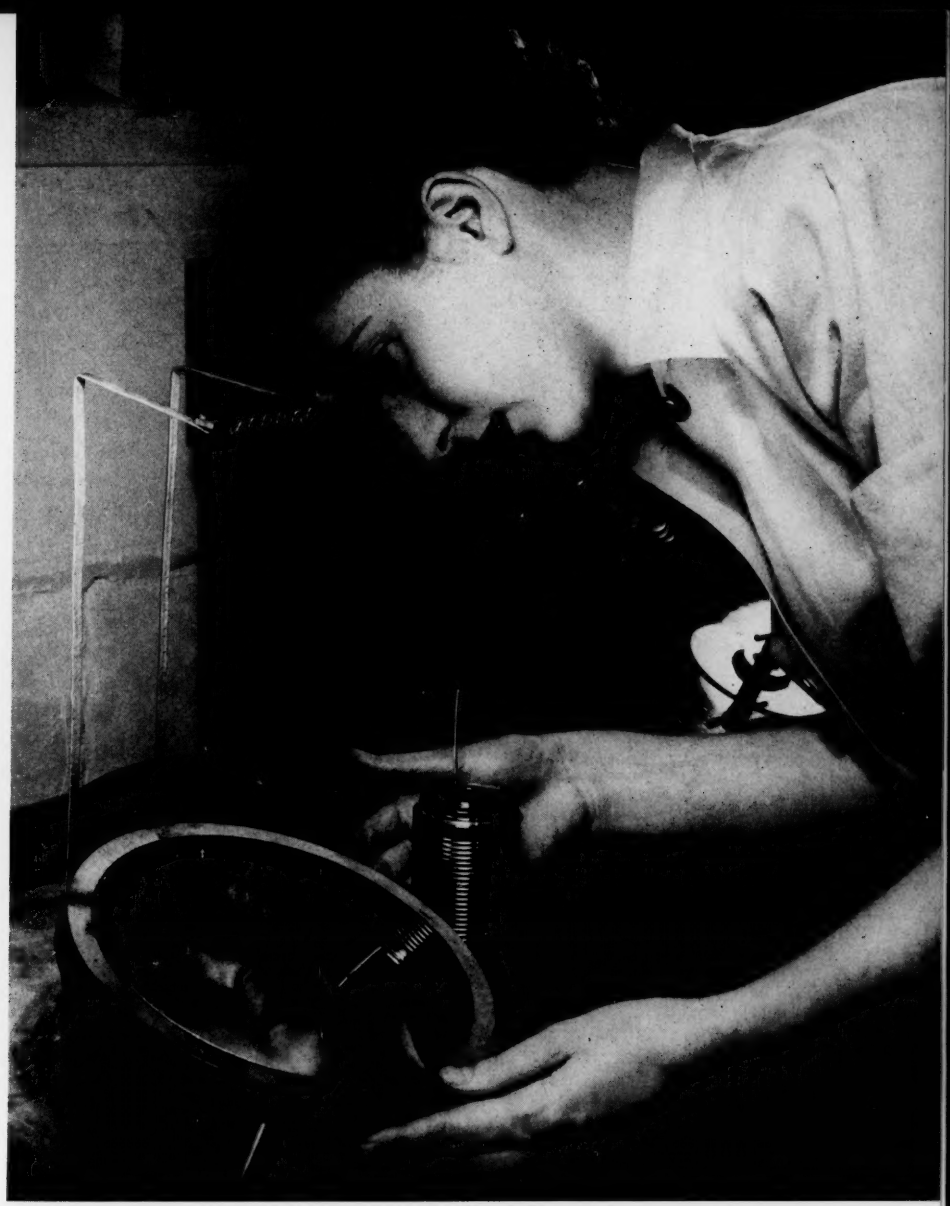
We decided to attempt to find a new method that would give us a more realistic sky. A first requirement was that the opaque plate be kept as thin as possible. We had done quite a bit of experimental work with high vacuum, and we knew that we could deposit aluminum on glass to make an opaque coating much thinner than .001 inch.

In our first attempt to reproduce stars we used an engraving machine. We tried to remove the aluminum coating at the desired positions on the plate, but this did not give a satisfactory result.

The next attempt involved the placing of diatoms on the clear surface of a glass plate, coating over them with aluminum, and then brushing them off. The process gave clean-cut holes in the metal film, but since the outline produced by the

The Academy's optics technician, Mrs. Frances M. Greeby, places a star-grain on a projection plate under the traversing microscope. (Moss)

A girl's trained eye and steady hand translated carborundum dust into the grand illusion of starlit skies under the Academy roof



FRANCES M. GREEBY

edge of a diatom was practically circular, the result was not appreciably better than that given by holes punched in metal.

In what can only be described as an inspiration, Dr. Hanna and his co-workers hit upon the idea of evaporating aluminum over carborundum grains. Such grains come in all shapes and sizes, but under a microscope they can be picked out as desired. In particular, we could pick up grains of the correct average diameter but with irregular outlines. When holes produced by such jagged grains are projected on a screen, sharp images bearing a striking resemblance to stars are formed.

The next task was to determine the grain sizes necessary to produce the various magnitudes of the stars. I made up test plates using selected grades of commercial carborundum. Mr. Salanave and I projected these on to the planetarium dome. From these projected images he decided on .0015 inch for 5.8 magnitude and .015 for first magnitude.

Instead of using a separate star plate we found that we could use the flat surface of the rear condenser lens.

▲ The author examines a star plate she has just removed from a vacuum chamber where the aluminum coating was deposited over the star grains. (Moss)

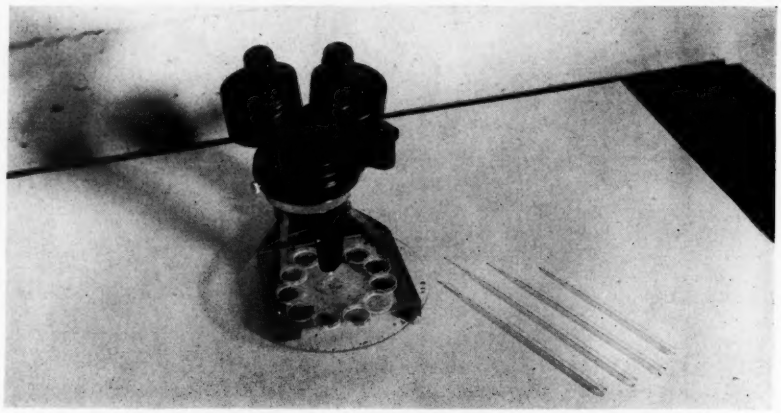
The mechanics involved in placing the grains in the correct positions required the construction of a special traversing microscope which was designed and constructed in our shop. This microscope contains two cross lines in the eyepiece, and it is moved horizontally by two micrometer screws set at right angles. One screw moves the microscope from right to left (X coördinate); the other moves it away from the operator (Y coördinate). Both are equipped with divided heads that record positions to inches and thousandths.

A jig was made to hold the condenser lens in a fixed position under the traversing microscope. I made up a reticle with lines reading from .0015 to .015 inch and mounted it in a dissecting microscope. In this way each grain could be measured before it was picked up.

The condenser was cleaned and placed in the jig under the traversing microscope. In order to know which stars to place on a given plate, I had already sorted each field of stars by means of the IBM cards which came from the computer. After first locating the corners of the plate by their X and Y coördinates, I proceeded by a simple graphic method to determine which stars were to fall within the plotted field boundaries. In these cases, the corresponding IBM card was pulled from the deck and reserved for the actual work of placing the carborundum grains on the glass.

When the cards for all the stars that were going on a particular plate had been pulled, I was ready to place the stars which they represented on the glass. Noting the magnitude of the star, I picked up a measured grain of the corresponding size under the dissecting microscope with the extremely fine tip of a drawn glass rod, and transferred it to the surface of the condenser lens. I then pushed it about until it came to rest under the pre-set intersection of the cross lines in the microscope. Displacements amounting to less than the thickness of a human hair had to be controlled by hand, and I often made as many as half a dozen tries before a grain came to rest in its assigned place.

Among the 32 plates which had to be made, the least number of grains placed was 69 and the most was 222. After all the grains for a star field were placed I would go back and re-check each grain to make sure that it had not been moved.



A dissecting microscope was used to sort carborundum grains according to size and shape. Fine-tipped glass rods were needed to handle the minute grains. (F. L. Rogers)

Then very carefully the condenser and jig were removed from under the microscope. The lens was placed in a vacuum chamber and covered with a full coat of aluminum.

After the grains were brushed off, the aluminum coating was sprayed with black lacquer. This was done to cover any holes resulting from dust or grains dropped in the placement process. After the lacquer was dry the condenser was replaced under the microscope in its original position. With a small cotton swab dipped in acetone I carefully removed the lacquer in only the places where the grains had been, leaving a clear aperture through the lacquer and aluminum.

As the reader can perhaps guess, the work I have described was tiring and exacting. It required anywhere from two and a half to three days to complete a star plate, and the work on all 32 of them was spread over a period of six months. I think it was with pardonable pride that I viewed the completed planetarium sky, with each little star shining brightly in its proper place. END

RUSSELL W. PORTER

[1871-1949]

DR. RUSSELL W. PORTER was widely known in scientific circles, both amateur and professional, for his marvelously detailed sketches of the 200-inch Hale telescope, which he helped to design. Born in Springfield, Vermont, on December 13, 1871, and trained for the profession of architect, this versatile man achieved a reputation as an Arctic explorer. He was with Peary in the polar regions, and with other expeditions to Greenland and Baffin Island.

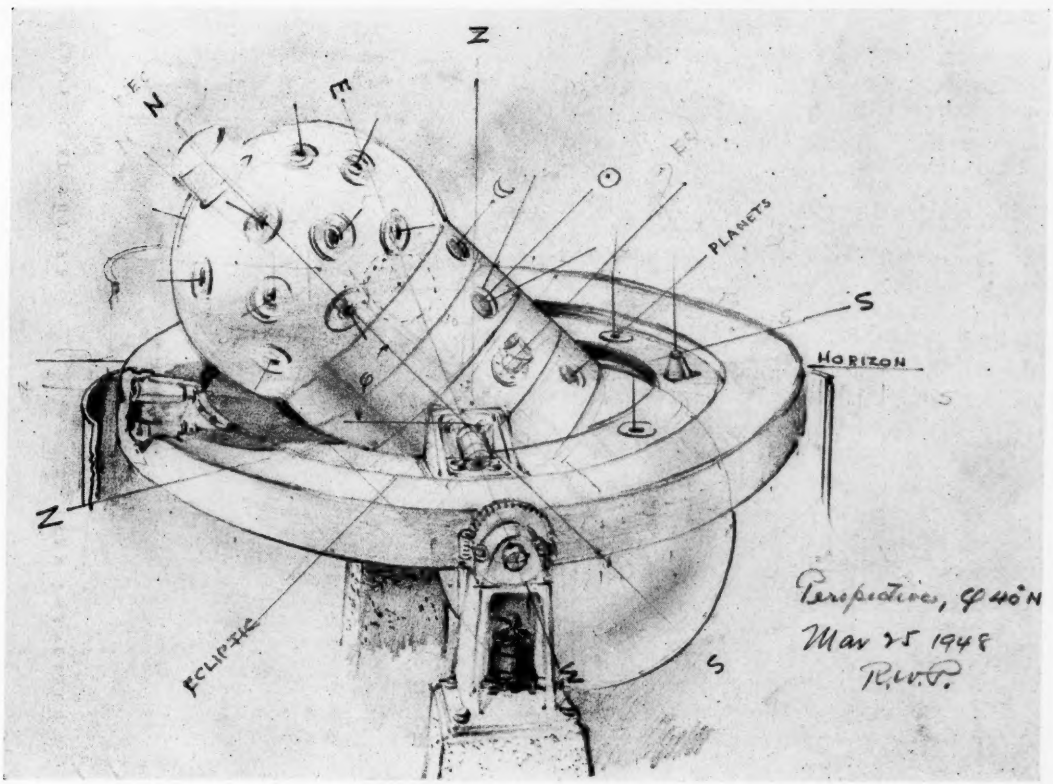
Before going to Pasadena and the 200-inch telescope project in 1928, he became well known for his efforts in organizing and assisting amateur astronomers. He was in fact considered one of the fathers of that hobby in this country.

Dr. Porter's association with the Morrison Planetarium project began in March of 1948. At that time the Trustees were uncertain about undertaking work of such magnitude in the Academy's shops. Dr. G. Dallas Hanna prevailed upon his long-time friend, Russell Porter, to come to San Francisco and act as a consultant in the early, planning stages of the projection instrument.

After a week of talking and thinking, Dr. Porter came up with the little sketch reproduced here. At the luncheon meeting Dr. Miller referred to in his article, he told the Trustees it was his considered opinion that the Academy could build a star projector equal to or better than the Zeiss instrument. To back up his statement, Porter passed around this sketch. Finally, so the story goes, Trustee Edward E. Hills handed the sketch to the Director, Dr. Miller, saying: "You had better keep this and have it framed; it's the first drawing of your new projector."

Dr. Porter did not live another year to see the fruits of his courageous counsel; he died on February 22, 1949.

LEON E. SALANAVE



A noted astronomer's sketch launched the Planetarium projector

Fig
tow
are

EARLE G. LINSLEY *Close-up of our nearest neighbor in space*

THE MOON *Exploring the moonscape of the first stop in man's future travels toward the other planets*

THERE are two questions asked most frequently by visitors viewing the moon at an observatory: How large is the moon? How far away is it?

In answering the first question this astronomer often asks the visitor, "How large does it appear to you as you see it in the sky?" Answers range from "the size of a nickel" to "the size of a washtub," the most frequent being "about the size of a dinner plate." These answers point out that individual judgments are of no value; there is no way to give the size except in figures.

The moon's diameter is 2,163 miles, more than one-fourth of the earth's. Its circumference is 6,795 miles.

The first photograph shows a view of one-quarter of the moon's surface, or one-half of the side of the moon that is always turned towards the earth. Shown in the picture are about 3,700,000 square miles – (the area of the United States is 3,022,387 square miles). From tip to tip in the picture the distance is approximately the same as from Portland, Me., to Portland, Ore.

A full moon reveals to us an area almost equal to that of the continent of North America.

The distance to the moon varies, for the moon moves around the earth in an elliptical orbit. At the farthest it is 252,710 miles from earth, at the nearest 221,463. The average distance is 238,857 miles. Astronomers, to give a figure that is easier to remember, commonly say that the distance is about 240,000 miles.

In reading the extensive literature on the moon you will find a number of unfamiliar terms. *Mona,* a word used by the ancient Saxons, gives us our word, *moon.* To the Romans our palefaced neighbor was *luna,* a name rarely used now although the adjective *lunar* is very common and convenient, since we have not derived an adjective from *moon.* To the Greeks the moon was *selene.* We have nouns, *selenography* and *selenology,* comparable to *geography* and *geology.*

Astronomers call our neighbor a *satellite,* meaning an attendant. Other terms used to describe various lunar features are all descriptive of features found on the surface of the earth: seas, craters, mountain ranges, isolated peaks, rills, clefts, rays, craterlets, crater cones, crater pits, walled plains, fault lines, scarps, and cliffs.

In studying relief features, the small diameter of the moon must be remembered and the consequent greater curvature of the surface compared with that of the earth. If the mountains on the earth were in the same proportion as those on the moon relative to diameter, Mount Everest would be approximately 22 miles high, instead of only six.

When the first man lands upon the surface of the moon one of the strangest aspects of his new world will be the lack of an atmosphere. In that eerie land where no sound can be heard, he will find no wind, no clouds, and no rain. Thousands of falling meteorites will shower the surface and shatter noiselessly and without leaving a luminous trail. (The resistance of our atmosphere causes most of these objects to burn or disintegrate before they reach the earth's surface.)

Rocks and mountains on the moon are not worn down by wind, rain, or ice. However, the visitor might see rocks shattering from the changes in temperature between the long day and the long night, and from the impact of an occasional large meteor. Sunrise and sunsets would come with unfamiliar suddenness, and the stars would be brilliant against a black sky.

Since space travel is impossible at this time, we can only observe. First to catch our eye are the pits or craters of which about 30,000 have been counted on the side of the moon that we see. These craters vary from 150 miles in diameter to a mile or less. There must be millions of smaller craters, too tiny to observe with existing telescopes.

A typical crater is circular with steep surrounding walls. These walls, which have the sharpest slopes on the inside, reach elevations of thousands of feet. Frequently the craters have interior pointed hills which resemble volcanic cones on earth except that they usually lack craters in the top.

Upon the probable origin of the moon craters much interesting literature is available. Theories vary, but the simplest approach is to compare them with features on the surface of the earth. In many respects they are comparable to volcanoes; therefore the volcanic theory of origin is a popular one.

The earth's volcanoes usually have great lava flows which have escaped either from the crater or from vents on the sides of cones. Such lava flows seem to be lacking on the moon; however, there are great relatively smooth areas away from the craters called *maria* which resemble surface lava flows known on the earth. In some selected areas, as in the Copernicus region, surface flows seem recognizable.

Supporting the volcanic theory is a recent elaborate and detailed description of areas on the surface of the moon made by a geologist. J. E. Spurr* states that the moon shows surface features we would call volcanic

*Spurr, J. E. *Geology Applied to Selenology,* 1945.

Fig. 1. The moon at last quarter. One half of the side of the moon that is always turned toward us is lost in darkness. The South Pole is near the top of the picture. Figures 2 and 3 are portions of this area. (Photos courtesy Lick Observatory, University of California)

if they were on earth. He writes: "They are sufficiently like those of the earth to be recognized as due to somewhat similar causes, while in their differences they illustrate the differences between the two bodies. The most important difference is that the igneous phenomena of the moon are records of stiffening and hardening of the original crust – the crusting over of a fluid sphere the last stages of which were quieted untold ages ago."

That meteorites caused the moon's craters is another theory.* Supporting this argument is their similarity in appearance, on an enlarged scale, to the Meteor Crater near Winslow, Arizona, and the belief that large and small meteorites have struck the moon in great numbers.

So much argument has been presented for both of these theories that space here does not even allow a summary. Let us put it this way. Here are pictured portions of the moon, clearly reproduced from photographs made with the 36-inch telescope at the Lick Observatory of the University of California. Let the reader study them and by comparing them with known features on earth form his own opinion.

We have to remember that observers never see anything happen on the moon which helps settle the discussion. If one active volcano would build up a cone or blow out a new crater while observers were watching – what a thrill and what a help we would have! The only sight to rival it would be to observe a huge meteorite strike the surface of the moon, smashing out a crater and ending the controversy at the same instant.

Since we can not give an answer which satisfies all as to how these features were formed, we shall have to content ourselves with describing some of the more conspicuous of them as shown in the three illustrations. Most conspicuous are the *maria* (seas), the dark areas on the moon which can be seen with the unaided eye. Often mistaken for shadows, they are areas of darker and smoother surface material which can be compared with lava flows or great lava plains

*See R. B. Baldwin, *The Face of the Moon* (University of Chicago Press, 1949).

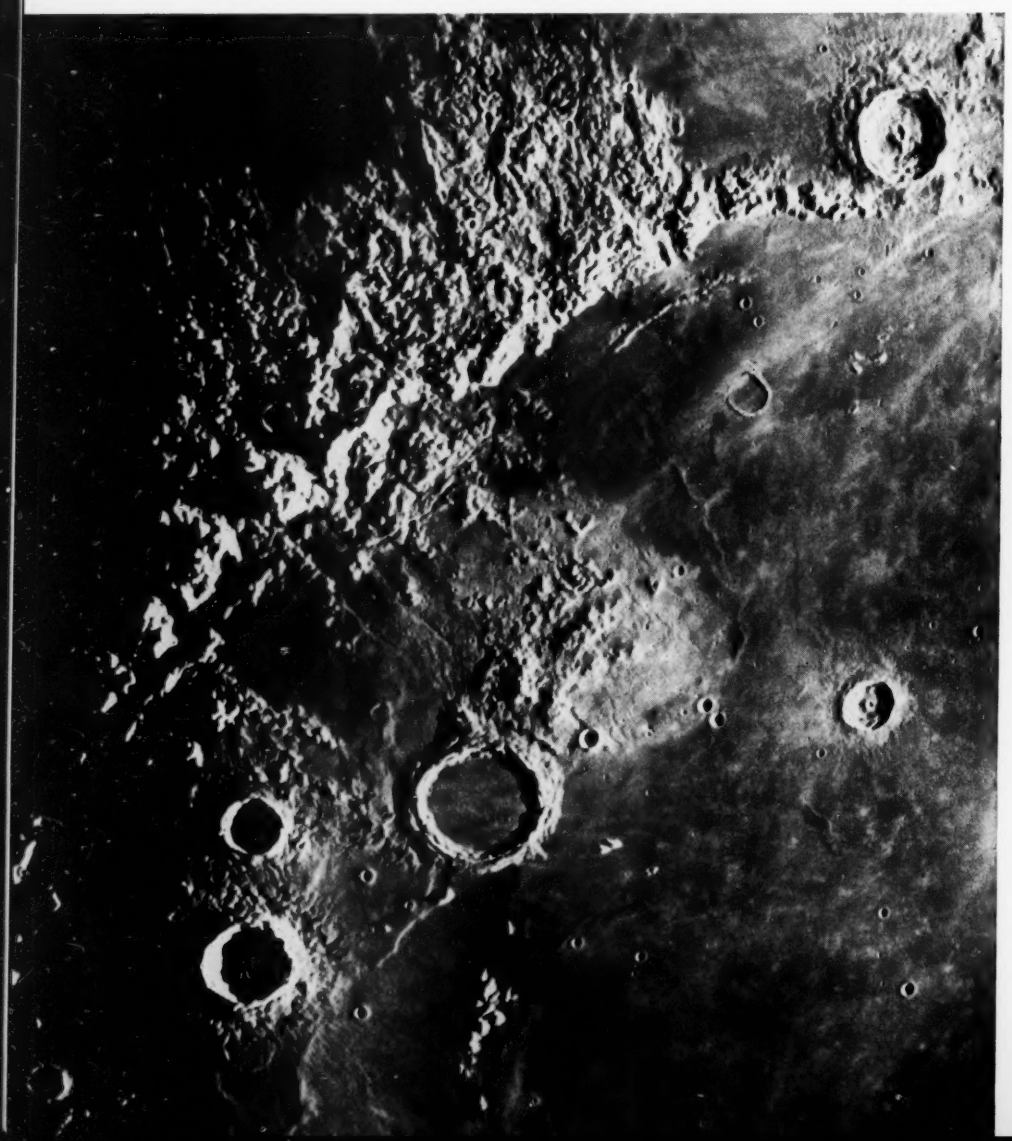


Fig. 2. A portion of the northeast quadrant at the last quarter. North is at the bottom, east to the right. The great curved mountain range is the Apennines. At upper right is the crater Eratosthenes. The Caucasus Mountains are near left center, and the Alps, lower left, are lost in sunset shadow. Archimedes, the great walled plain, is in lower center.

Fig. 3. Copernicus and surrounding area, with shadows of late afternoon falling onto the crater floors. The radiating rays show plainly.

on the earth. Early astronomers, seeing their surfaces indistinctly, thought they might be seas. The name still clings, although most observers wish it could be dropped.

There are 14 easily recognizable dark areas which still carry their fanciful Latin names. Among them are *Mare Serenitatis* (Sea of Serenity), *Sinus Iridum* (Bay of Rainbows), and the largest of all, *Oceanus Procellarum* (Sea of Storms). In these dark plains are numerous pits, deep clefts, and summits of partly submerged mountains.

The mountains of the moon have been named after those of the earth. Chief among them are the Apennines, a range approximately 450 miles long. The lunar mountains are characteristically steep on one side with a gradual slope on the other side. There are thousands of peaks in them, some rising to heights of 20,000 feet.

Turning from mountains to craters, it can be seen that Archimedes, the largest circle in our second photograph is a ring plain 50 miles in diameter. It has many features in sharp contrast with Copernicus in the last figure. Archimedes has walls about 4,000 feet high, and they are more massive than those of Copernicus. The crest line of Archimedes is more irregular, and great terraces appear on both sides of the rim. The outer slope extends for about seven miles. On the crest are several depressions. A deep cleft makes it appear double for many miles.

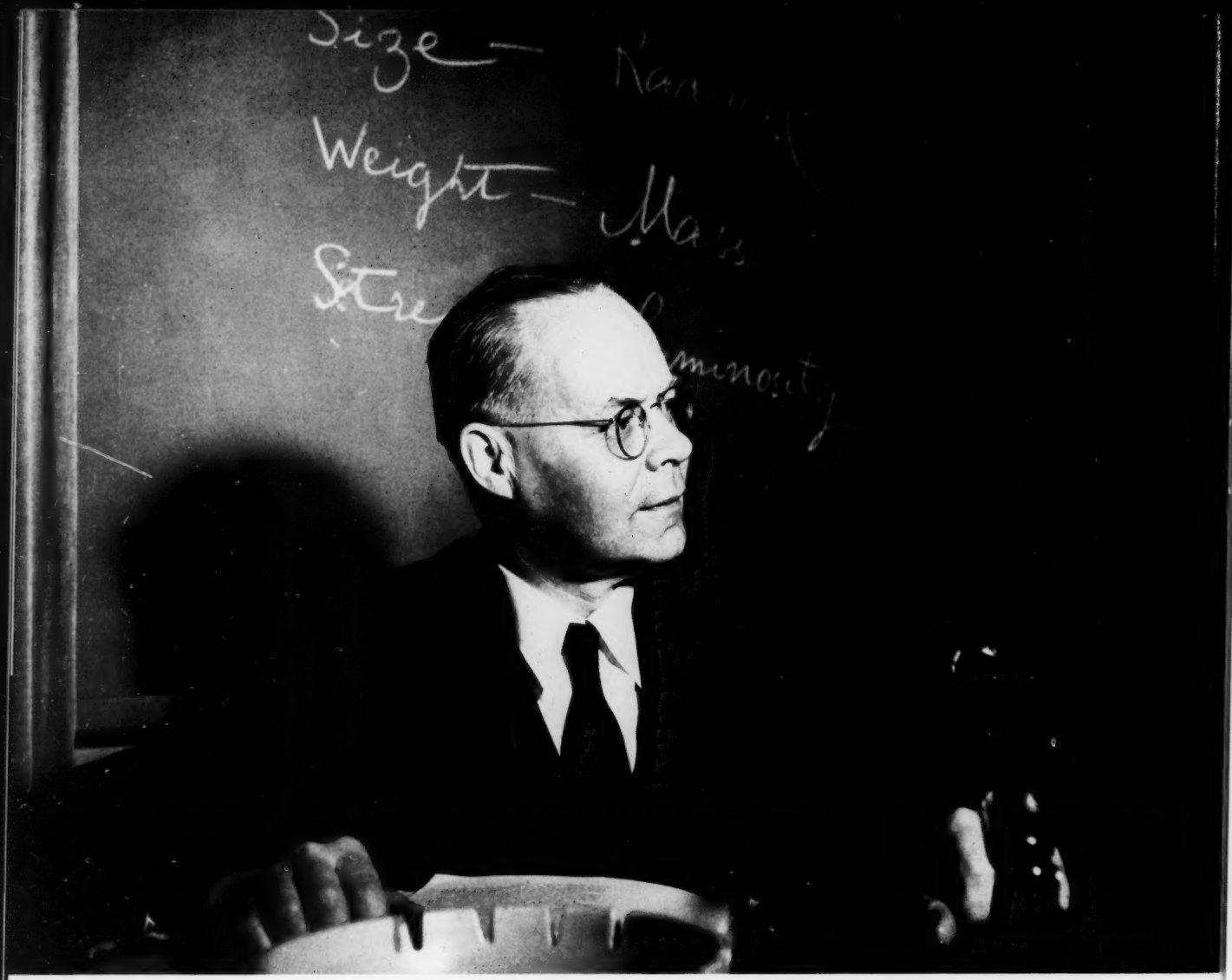
On the southeast for 100 miles is a ragged rough area which becomes very white under high sun. While the area between Archimedes and the Apennines seems quite smooth, there are many deep clefts, some easily recognized, others appearing as fine lines.

Copernicus is the central feature of the last figure, but it can be identified a little off the center in the first. This is a nearly circular plain apparently below the general level of the surrounding surface. Surrounded by a rugged mountain wall 56 miles in diameter, it stands out in nearly solitary grandeur. Its surrounding wall is almost circular, although a suggestion of a polygon may be detected. Thin and sharp in many places, the wall has peaks which reach elevations of 12,000 feet above the floor. In the center, from the floor which usually appears darker than the surrounding area, there rises a cluster of mountain peaks, three of which are easily recognized.

Looking at Copernicus in figure 1, one discovers a system of rays which radiate from the crater. Shown in greater detail in figure 3, they cross ridges, folds, depressions, and mountain ranges. The rays are most conspicuous when the sun is high and very difficult to see when the sun is low. It seems reasonable to believe that these streaks are light colored fragments scattered as a result of some great explosion.

Here we have described but a few of the characteristic features of the moon. Many of them, however, can be seen easily with a good pair of binoculars held in a steady position. A small telescope reveals still more in interesting detail. It is hoped that our readers will view with new interest our silent, silver neighbor in space.

END



Biographer of Stars

ON THE SCALE of the universe, a young star may be ten million years old before its light reaches the earth. Comets travel faster than a million miles an hour. If the work of a man is remembered on earth a thousand years, it will be for a moment on that scale. In the opinion of his astronomical colleagues, Otto Struve may well be remembered ten centuries hence as one of those who led toward surer knowledge of the universe.

The forces determining one man's place in the ages are imponderable. It can be surely stated, however, that Otto Struve's research in astro-physics—the "new" thirty year-old science – has given fresh impetus to our generation of astronomers everywhere. This generation is well on the way to understanding the evolutionary processes of the stars. It has determined that our galaxy came into being some three billion years ago – or, at any rate, that some tremendous cosmic change took place at about that time. Changes since then have been evolutionary, not revolutionary. There are young stars, and there are old stars, small stars like our sun, supergiants like Antares. New stars are being created all the time, old stars are dying. One of astronomy's greatest thrills, Dr. Struve feels, is to observe these changes. For in a sense, he says, you are watching Creation.

There is in this attitude a deep humility which is characteristic. Otto Struve dislikes having undue im-

Otto Struve, astronomer and teacher. (C.A.S. Photo – Moss Studios)

portance attached to his work. One of the Academy's Planetarium staff was present this fall at a colloquium of astronomers at the University of California, Berkeley, when Dr. Struve reported on the recent triennial meeting of the International Astronomical Union in Rome. At the conclusion of his detailed account of the proceedings of this most august of the world's astronomical bodies, one of his fellow astronomers jumped up to say something to this effect: "Dr. Struve has failed to mention one of the most important results of that convention. He was elected President of the International Astronomical Union!" That is the highest honor world astronomers can bestow on one of their fellows.

Dr. Struve shares the opinion that men's minds are no greater today than they were in earlier times. "We have accumulated more knowledge, we have better training, and certainly finer instruments are available to us. But as men, we are essentially the same," he says. Once, when his accomplishments were praised, he replied: "There are many men responsible for any one man's work — those who have taught him and those whose research and background materials make it possible for his generation to move forward."

A fourth-generation sky watcher, Struve has kept pace with his distinguished forebears. In three out of four generations a Struve has had charge of the greatest refracting telescope of his time. Great-grandfather Friedrich Georg Wilhelm Struve, in 1820, was given the honor of working with the 9½-inch refractor at Dorpat (now Tartu, in Estonia). And as director of the new observatory at Pulkovo, near St. Petersburg, he had installed there a 15-inch refractor. Grandfather Otto Wilhelm succeeded to the Pulkovo directorship in 1862, and in 1885, five years before he retired, he saw the great 30-inch refractor installed at Pulkovo. This was the world's largest until the 36-inch refractor was set up in California's own Lick Observatory in 1888. Father Ludwig was professor of astronomy at the university in Kharkov when young Otto was born there in 1897 (Uncle Karl Hermann, Ludwig's brother, had succeeded the elder Otto at Pulkovo in 1890).

With the love of astronomy his father had instilled in him, young Otto Struve came to the United States after the Bolshevik Revolution, and in 1921 became an assistant in stellar spectroscopy at the University of Chicago. By 1932 he had worked up to the directorship of Chicago's Yerkes Observatory, which gave him charge over the 40-inch telescope at Williams Bay. The huge Yerkes instrument was then, and still is, the world's largest refracting telescope.

Struve's studies on double stars, discoveries in the theory of stellar evolution, have been his long-range contribution to understanding the origin and nature of the universe. Like most research astronomers, he spends only a small part of his time at the telescope. The traditional instrument has been teamed up with the spectrograph, a photographic device that records the light of a star in a spectrum. Pictures thus obtained give clues to the composition of a star, its temperature, and other essential data. Struve has built his own instrument for reading these photographic records. He calls it a comparator for it is used to read a pair of negatives — spectra of two stars or spectra of the same star made on two different occasions.

Dr. Struve's coming from Chicago in 1950 to head the University of California's Department of Astronomy is owing to another side of his nature. This is surprising for a researcher who has staked out quantities of work for himself, more than could be done in a hundred years — he believes it important that he spend a good share of the second half of his life teaching. Dividing his time between the Berkeley campus and research work on Mt. Hamilton and Mt. Wilson, he complains there isn't time for all the things he knows must be done. "As you may have guessed," he says, "there are many lifetimes of research yet ahead for the astronomer."

BENJAMIN DRAPER

Left to right: **Friedrich Georg Wilhelm Struve, Otto Struve, Ludwig Struve.**

Chemical analysis of planets

THE PLANETS: *Their Origin and Development.* By Harold C. Urey. Yale University Press, New Haven. 1952. xvii + 245 pp., 4 appendices, map. $5.00.

MEN OF SCIENCE generally, and astronomers in particular, often disagree sharply in their professional work. On the other hand, they frequently find themselves in harmony and can make statements without fear of contradiction. That the origin and development of the sun's planetary system is one of the most difficult problems in the realm of natural science is a proposition none will dispute; that Dr. Urey's latest book brings stimulating new ideas to bear on this problem is another point of assent, however much one may disagree with some of the details of his argument.

In six very full chapters Dr. Urey discusses the historical background of his subject, the physical features and probable evolution of the moon and the so-called *terrestrial* planets, abundance of elements and chemical processes involved in the system, and the internal heat of the earth. The major planets (Jupiter, Saturn, Uranus and Neptune) are not emphasized because, as Urey states, their chemical composition and physical properties are rather uninformative about the processes by which they were created. To understand the basis of this statement, one must follow through the salient points of the author's thesis.

Dr. Urey is one of the world's foremost chemists; in 1934 he was awarded a Nobel Prize for his work with heavy hydrogen. As he describes his entry into the field of speculation on planetary origins, it was an outgrowth of certain studies he made on the distribution of both the heat and the chemical elements in the earth. It occurred to him that, given present knowledge of earth chemistry and chemical processes occurring at various temperatures and pressures, it should be possible to *deduce* the physical and chemical circumstances that must have existed during the birth and evolution of planets like the earth. The development of evidence in support of this view resulted in this book.

Roughly half of this volume, in the opinion of this reviewer, can be studied with profit by anyone who has a good knowledge of facts about the solar system, as well as some understanding of the bases of physics and chemistry. The remainder is not for the casual reader! The review of present theories of the moon's origin, the copious and detailed references in the text, and the factual appendices are themselves worth the price of the book.

To top it off, the book gives the reader insight into the methods of science (inductive thinking, if it must be pigeon-holed) when applied to a very difficult problem. Dr. Urey, unlike some scientists who expound on their pet theories, is very careful to segregate established facts from his own speculations; this is perhaps the best part of all.

LEON E. SALANAVE
Morrison Planetarium
California Academy of Sciences

Stars on your shelf

A BOOKSHELF FOR STAR-GAZERS OF ALL AGES—The following list of books and study materials in astronomy has been compiled for *PD* readers by Leon E. Salanave, lecturer in the Morrison Planetarium. These references are listed with the most elementary books at the beginning. (Asterisks mark titles usually on sale at the Planetarium.)

**The Basic Science Education Series — Astronomy.* Separate titles on the sun, moon, planets, and stars. Row, Peterson & Co., Evanston, Illinois.

For ages 8 - 14.

**A Dipper Full of Stars: Beginner's Guide to the Heavens.* By Lou Williams. Follett Publishing Co., Chicago.

For high school age and older; very nicely done up.

**The Stars: A New Way to See Them.* By H. A. Rey. Houghton Mifflin Co., Boston.

Star-gazing with a touch of humor; high school and older.

**Discover the Stars.* By Gaylord Johnson. Sentinel Book Co., 112 E. 19th Street, New York.

How to make simple devices for observing the stars and learning astronomy.

**Handy Star Finder.* By C. S. Hammond Co., Maplewood, New Jersey.

An all-year map of the stars; handy to have around.

**New Handbook of the Heavens.* By Bernhard, Bennett, & Rice. New American Library, 501 Madison Ave., New York 22.

Good beginning, especially for anybody interested in observing the heavens through a telescope.

**A Beginner's Star Book.* By Kelvin McKready and Maud K. Murphy. G. P. Putnam Co. 1937 edition.

Excellent accessory to star-gazing with aid of binoculars or small telescopes.

The Universe Around Us. By Sir James Jeans. Macmillan Co. 1945.

A classic in the popular exposition of astronomy and related sciences, by one this century's great astronomers.

**Birth and Death of the Sun.* By George Gamow. Viking Press. 1945.
**Biography of the Earth.* By George Gamow. North American Library. 1948.

Two books by an eminent authority on cosmology; very entertaining reading.

**Conquest of Space.* By Willey Ley. Viking Press. 1949.

About rockets and the future of interplanetary travel; technically correct, on the whole, and free of unscientific speculations. Beautifully illustrated by Chesley Bonestell.

Star Atlas and Reference Handbook. By Arthur P. Norton. Gall & Inglis (London). 1946.

Unsurpassed as a guide for the serious telescope-using amateur astronomer.

Making Your Own Telescope. By Allyn J. Thompson. Sky Publishing Corporation, Cambridge 38, Mass. 1947.

Basic information on the construction and use of a home-made reflecting type telescope.

Harvard Books on Astronomy; a series by various authors. Blakiston Co., Philadelphia. 1943 –.

Cover all fields of modern astronomy in an authoritative way; written for laymen by experts.

The Astronomical Universe. By Wasley S. Krogdahl. Macmillan Co. 1952.

Approaching the study of astronomy through basic principles of physics; a college text-book of exceptional merit.

Astronomy. By Russell, Dugan, and Stewart. (2 vols.) Ginn & Co. 1926 and 1945.

Still considered by many astronomers the best textbook on the fundamentals of their subject, although revision of the part on astrophysics is much needed.

Foundations of Astronomy. By W. A. Smart. Longmans, Green & Co., New York. 1942.

Introducing some of the mathematical bases of the science.

Radio Astronomy. By Bernard Lovell and J. A. Clegg. John Wiley & Sons, Inc. 1952.

On the newest branch of astronomical investigation; the most important instrumental development since the inventions of the spectroscope and photography.

* * *

Sky and Telescope Magazine. Published monthly at Harvard College Observatory, Cambridge 38, Mass.

Outstanding astronomical periodical for laymen produced in this country.

Peelings for your weather eye

WIND, STORM AND RAIN: *The Story of Weather.* By Denning Miller. Coward-McCann, Inc., New York. 1952. xiii + 177 pp., diagrams, 8 full-page cloud photographs. $3.95.

Not since Wenstrom's *Weather and the Ocean of Air* (1942) has this reviewer held in hand a book about the weather that so invited reading. Regrettably, Denning Miller's attractive little book did not arrive until the week of going to press with this issue, so a fair and adequate review is not at once possible. But, as in our Academy's new Hall of Science, meteorology is linked with astronomy – both deal with aspects of the sky; we therefore hasten happily to get a weather book into these pages before the last form closes for the press-run.

In his Preface, Ernest J. Christie, Meteorologist in Charge, U. S. Weather Bureau, New York, points out that it is the responsibility of everyone who *uses* the forecasting and meteorological services furnished by the Government "to obtain the best practical advantage" from them. "To do this," Mr. Christie says, "he should become familiar with the development of the weather and the way it changes, so that he can properly evaluate the information supplied by the Weather Bureau." Mr. Miller's book is recommended for enjoyment of "the experience of learning, easily and pleasantly, how Mother Nature sets up the air-mass machinery to produce this thing called weather."

Our reading so far assures us that this former World War II naval air navigator is fully qualified to deal both au-

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thoritatively and entertainingly with the nature of the atmosphere and how it makes life possible, how the air moves about the world, air masses and how they are bred, fronts and frontal storms, how the clouds form and what they are called, how winds adjust the atmospheric pressure, the air aloft and the jet stream, weather within the tropics, and hurricanes, weather maps and what they tell, and how to forecast the weather – to run down the subtitles of his chapters by way of summary.

Farmers and fliers live and work by the weather. Some people seem to live in spite of the weather, to judge by their constant complaints. For all of us, knowledge can dispel the mystery yet enhance our appreciation of the grandeur and beauty – and our awe of the sometime terror – of this greatest show on earth, the ceaseless drama of wind, storm, and rain. D.G.K.

Highroads of history

THE STORY OF AMERICAN ROADS. By Val Hart. William Sloane Associates, Inc., New York. 1950. 243 pp., 42 photographs, 4 maps. $3.00.

"Mother, where do roads start and where do they end?" Val Hart's daughter asked her one day. Not having a short answer handy, this Virginian sensed that it would take a book to deal with the question adequately. The result is one that her daughter's contemporaries can enjoy and understand, but one also that need not be classed as a juvenile just because it is clearly and simply written.

From the light tracery of game trails and Indian hunting paths to the dense network of three million miles of automobile roads – what a span of American history that connotes, and what changes on the face of the continent! From *Los Caminos Reales* of the Spanish South and West and the portage paths of French fur traders, and the Boston Post Road (six miserable days from Bowling Green to Beacon Street!), Wilderness Road, Lancaster Pike, and Natchez Trace, down to the great westward routes of continental conquest – Santa Fe, Oregon, and Mormon trails, – down to the Lincoln Highway, Alaskan Highway, Pan-American Highway System, the author has skilfully managed a road-show of history with a revolving cast of Indians, conquistadors, colonists, pack-train and Conestoga wagon drivers, pony express riders, GI's in the Yukon muskeg – the generations of people on the move who built, traveled, lived and died on these roads.

Here, too, are the Erie Canal, and the first railroads, and the many odd ways by which Americans moved – rolling roads, for instance. Rivers were roads from the earliest times, and still are. It was the railroads that ended the first great era of wagon-road building, and led into a period of decay. It was the organized efforts of mid-Victorian bicyclists that began to get us out of the mud—efforts that paved the way, literally in time, for motorists. It is hard for us to believe today – so casually do we hit the super-highway and do four or five hundred smooth miles at a stretch, day after day – that "in 1908 there were only 650 miles of macadam roads in the entire country, and no concrete roads at all." The great road-building boom, in fact, came as late as the 1920's and 1930's, following the Federal-Aid Road Act and the Federal Highway Act.

Today we are at another turning point, the author concludes, "but at least" – as a result of the nationwide highway planning survey begun in 1936 by the Public Roads Administration – "we know now what is needed and what we have to do. The federal government has appropriated vast sums for road building, and long-range planning gives some assurance that when we do have these expressways," – "now mostly in the blueprint stage" – "they will not become obsolete before they wear out."

Looking into the future, Val Hart sees the time when "the old frontiers on the North American continent are gone – motorists may drive in comfort and safety from any place in the United States north to Alaska, and see the midnight sun of the Arctic Circle; or south to the Panama Canal and see the Southern Cross of tropic night skies."

For her appendix, the American Automobile Association has compiled the "Routes of Principal Named Highways in the United States." We recommend reading this book before your next long motor trip. D.G.K.

Facts with feathers

OUR AMAZING BIRDS: *The Little-known Facts About Their Private Lives.* By Robert S. Lemmon. With 102 paintings in black and white by Don R. Eckelberry. The American Garden Guild and Doubleday & Company, Inc., Garden City, New York. 1952. 239 pp. $3.95.

If you are looking for a handsome Christmas gift book for a friend who is an ardent amateur of bird lore, this one will undoubtedly catch you eye on the book counter. It is in no sense a field guide. Mr. Lemmon, who learned his birds under Frank M. Chapman, and Don Eckelberry, illustrator of the *Audubon Bird Guide* and *Audubon Water Bird Guide,* have collaborated on a crisp word-and-graphic treatment of 102 of our birds to which, because of their (the birds') various idiosyncrasies, they have chosen to apply the overworked tag "amazing" à la *National Geographic* and Audubon Screen Tours titles.

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ERRATA

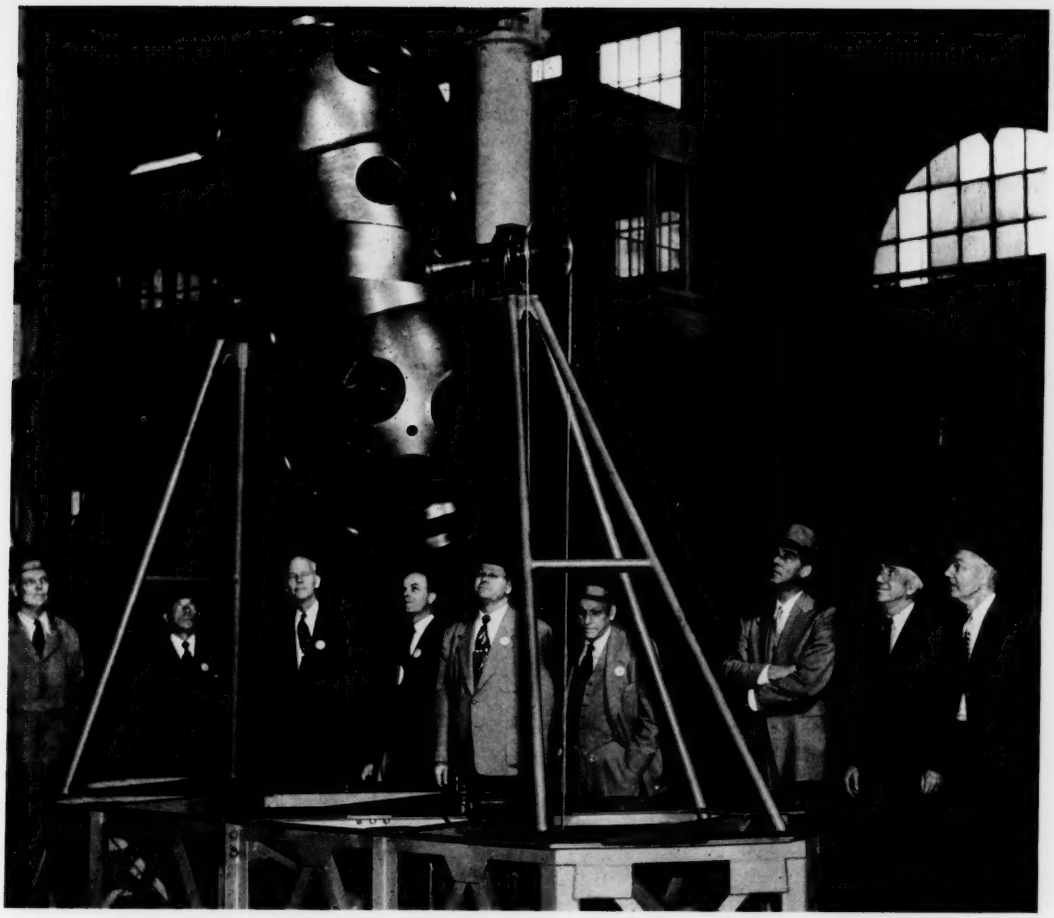
July-August 1952 — page 1 (THE COVER COPY): In the absence of indicated credit on the koala photographs, we credited them to the author, Ken Stott, Jr., knowing him to be an excellent animal photographer. Our "koala issue" drew the following letter from Mr. Stott (dateline San Diego Zoo, 30 July):

"The koala layout and cover were splendid and we (collectively and individually) hereby register appreciation. However, just for the record, I hasten to set you straight on a couple of points. First, the photos were taken by Richard Van Nostrand, the zoo's photographer. Second, if anybody at this end of the line reads the remarks in DISCOVERING PD'S AUTHORS, I shall either get promptly fired or a whale of a raise. In the first place, my "staff" consists mainly of me, and in the second place, the fact that we obtained the koalas is due to Mrs. Belle J. Benchley, director of the zoo, and the responsibility for maintaining them is almost entirely hers.

"With best regards, and thanks again for a swell layout."

Editorial apologies to Mrs. Benchley and to Mr. Van Nostrand. We hope Ken Stott gets a raise.

November-December 1952 — page 19 (photo caption): FOR 24 in the diagram opposite READ 1 in the diagram opposite.



Executives from California Academy of Sciences and Bethlehem Pacific's San Francisco Shipyard examine completed preliminary work on planetarium projector in the Yard's Machine Shop. Left to right are E. E. Erickson, Bethlehem Pacific Machinist Supervisor; Edward E. Hills, President of Hills Bros. Coffee, Inc., and Trustee of the Academy; A. S. Getten, Instrument Designer on the Academy staff; Raymond W. Greeby, Instrument Maker on the Academy staff; Alvin C. Gundred, Academy Electronics Engineer; Dr. G. Dallas Hanna, Superintendent of the Planetarium project; T. C. Ingersoll, General Manager of Bethlehem Pacific's Shipbuilding Division; Felix Conlin, Bethlehem Pacific's Machinery Superintendent; and Peter MacDonald, General Foreman of the San Francisco Yard Machine Shops.

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